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Thiokol CHEMICAL CORPORATION

C-1 ENGINE FINAL REPORT

Prepared for George C. Marshall Space Flight Center
Under Contract NAS8-15486

PROPELLANT VALVE QUALIFICATION

Volume I

Report RMD 6203-Q2

17 July 1967

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DENVILLE, NEW JERSEY

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Thiokol
REACTION MOTORS DIVISION

C-1 ENGINE PROGRAM

QUALIFICATION TEST REPORT

FOR

BIPROPELLANT AND QUADREDUNDANT VALVES

FINAL REPORT RMD 6203-Q2

VOLUME I

Prepared for George C. Marshall Space Flight Center
Under Contract NAS8-15486

17 July 1967

N68 22530

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STATEMENT OF QUALITY ASSURANCE

The tests described in this report were conducted under the control of the Quality Assurance Department of Thiokol-RMD. These tests were conducted in accordance with Contract End Item Specification (CP 15166) and procedures mutually agreed upon between NASA and Thiokol Chemical Corporation.

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Quality Control Supervisor
C-1 Program

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1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this report is to document the qualification test program conducted on the bipropellant and quadredundant propellant control valves which are component parts of the C-1 Engine.

The bipropellant valve, Thiokol - RMD Part No. 316305-200 has completed the qualification test requirements defined in Contract End Item Detail Specification CP 15166. The completion of these tests qualifies the bipropellant control valve for space use on the C-1 Engine. Thiokol - RMD Specification EC 20517 describes the bipropellant valve qualification requirements.

The quadredundant valve, Thiokol - RMD Part No. 317013-500 has completed the qualification test requirements defined in Contract End Item Detail Specification CP15166, except for vacuum, where the unit failed to pass the dielectric strength test. The quadredundant valve is therefore conditionally qualified for space use on the C-1 Engine. Thiokol - RMD Specification EC 20518 describes the quadredundant valve requirements.

1.2 CONTRACTUAL COVERAGE

The effort reported herein was conducted for the George C. Marshall Space Flight Center under NASA Contract No. NAS8-15486.

1.3 BACKGROUND

The scope of the C-1 Engine Program has undergone considerable transformation since the start of the Phase II contract in October 1965. Originally, the development of a multipurpose engine operable in either a pulsing or steady state mode was planned. However, as the C-1 Program progressed, both engine and program requirements were realigned.

The qualified C-1 Engine design described in Thiokol - RMD Final Report 6203-DR3 is a high performance engine having unlimited restart capability. The C-1 Engine operates in a steady state mode and can deliver pulses ranging from 2 seconds to 2000 seconds duration with a 50-minute off time between pulses. Although the C-1 Engine design was substantially realigned during the course of the development program the requirements for the propellant control valves as defined in Thiokol - RMD Specifications EC 20517 and EC 20518 remained essentially unchanged throughout the course of the program.

The Valve and C-1 Engine Development Programs were carried out concurrently to insure that the propellant control valves were specifically tailored to the C-1 Engine requirement. The Development Program to demonstrate the design integrity and basic functional characteristics of the bipropellant and quadredundant valves is reported in Thiokol - RMD Final Report 6203-F1.

Part I of this report discusses the Qualification Test Program of the bipropellant valve and Part II discusses the Qualification Test Program of the quadredundant valve. The following section presents a brief description of each propellant valve.

1.4 DESCRIPTION OF VALVES

The C-1 Engine utilizes either a bipropellant valve or a quadredundant valve, both designed and manufactured by Moog, Inc., East Aurora, New York. The valve can be readily removed from the engine to permit substitution of the alternate valve configuration.

1.4.1 BIPROPELLANT VALVE

The design of the bipropellant valve shown in Figures 1.4.1-1 and 1.4.1-2 is based on a unit (Moog Model 52-108) previously built and tested for the NASA Manned Spacecraft Center, Houston, Texas. The bipropellant valve employs a torque motor to simultaneously open and close the fuel and oxidizer ports by using a movable flapper. The ports are arranged in separate, fluid sealed chambers that completely isolate the fuel and the oxidizer. The flappers are mounted in separate flexure tubes and are attached to a common armature which mechanically links the flapper assemblies so that two propellants may be controlled simultaneously with one torque motor.

The torque motor features a permanent magnetic flux circuit which polarizes the armature and is energized by power to produce an output torque proportional to input current. The valve can be operated with either the primary or secondary coil. The primary coil comprised of two separate coils is designed for high response actuation while the secondary coil, designed for lower current and slower actuation, consists of a single coil.

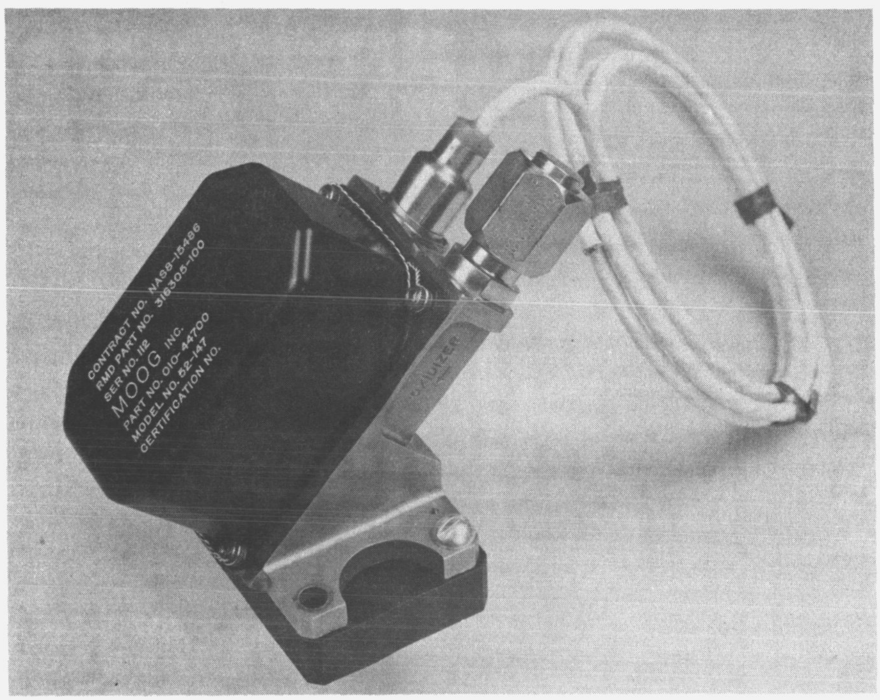


Figure 1.4.1-1. Bipropellant Valve

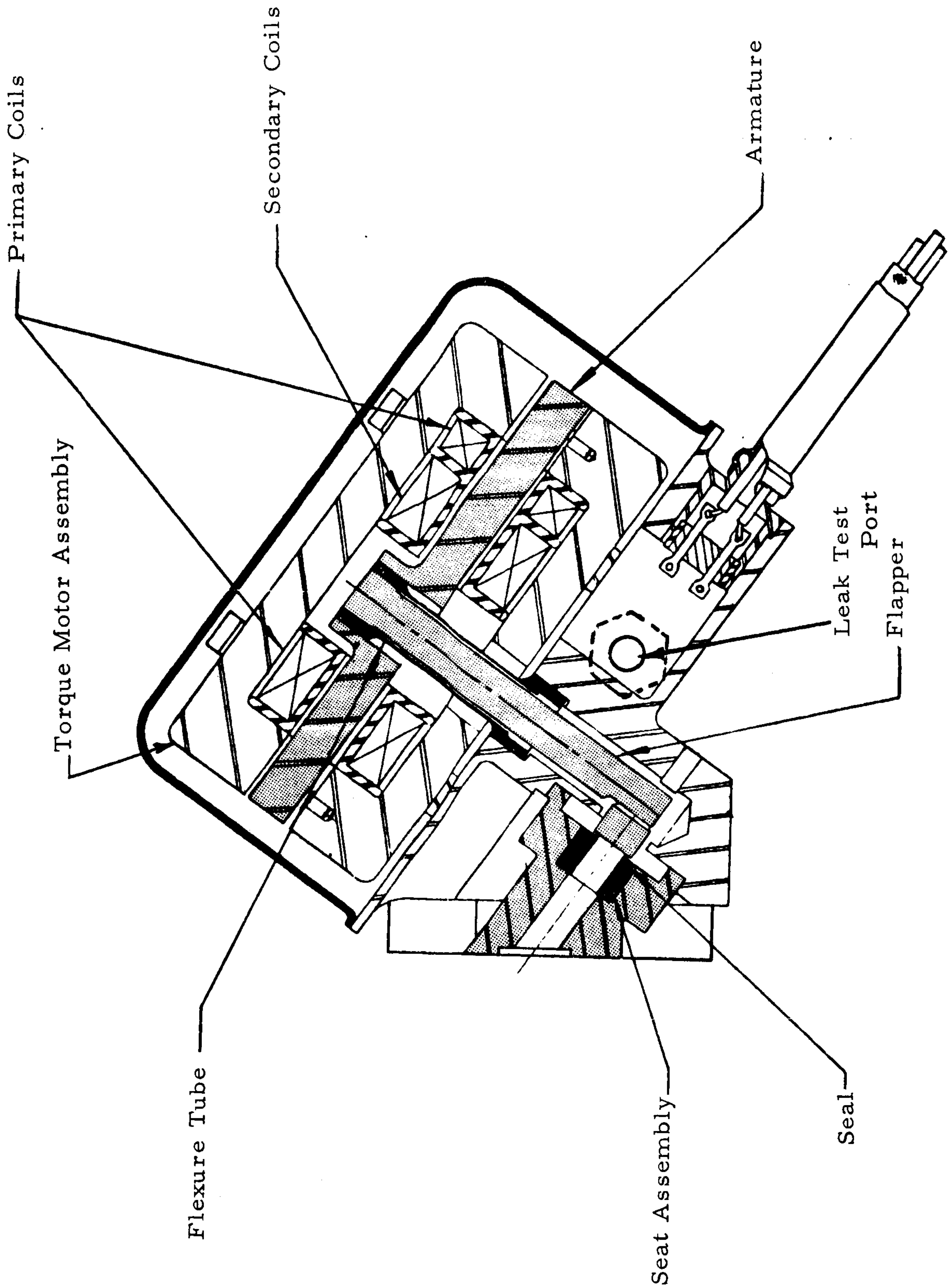


Figure 1.4.1-2. Bipropellant Valve Cross-Section

The valve is opened by energizing the torque motor which results in moving the flappers off the ports. The electrical input is designed to saturate the magnetic circuit of the torque motor so that a very high driving force results. This force moves the flappers against stops which are preset to give the precise pressure drop required across the valve.

Removal of the electrical signal permits the flappers to return to closed position. Symmetrical on and off transient characteristics are obtained by matching the magnetic bias force to the net driving force from electrical signal input. Torque motor design establishes the bias force so that no adjustments or separate bias springs are required. In the de-energized position, the valve remains closed by magnetic bias which causes the flappers to seal both fuel and oxidizer ports for indefinite periods with or without fluid pressures.

1.4.2 QUADREDUNDANT VALVE

The design of the quadredundant valve shown in Figures 1.4.2-1 and 1.4.2-2 consists of two separate bodies, one oxidizer and one fuel, with each body containing four identical individual torque motor operated valves integrally manifolded. The manifolding provides redundant series-parallel flow paths within each body. The quadredundant valve utilizes a single air gap type torque motor to open and close each of the eight flow control ports.

The torque motors used in this valve contain a polarized magnetic flux circuit generated by two permanent magnets arranged in series. The motor armature extends into the air gap of the permanent magnetic flux circuit and is supported in this position by the flexure tube. When the single coil assembly surrounding the armature is energized, the resulting current flow increases the flux in one air gap and reduces the flux in the other air gap thereby producing an output torque proportional to input current. The driving torque holds the armature flapper assembly in the open position against the flapper stop. When the torque motors are de-energized the magnetic bias returns the armature flapper assembly to the closed position.

The quadredundant valve incorporates the flexure tube design in much the same manner as the bipropellant valve. The flexure tube isolates the electrical motor assembly from the propellants and thereby eliminates possible deterioration of the electrical materials and contributes to the long-life and long-storage capabilities. Additionally, the design contains no close fitting sliding parts thus eliminating propellant gumming failures.

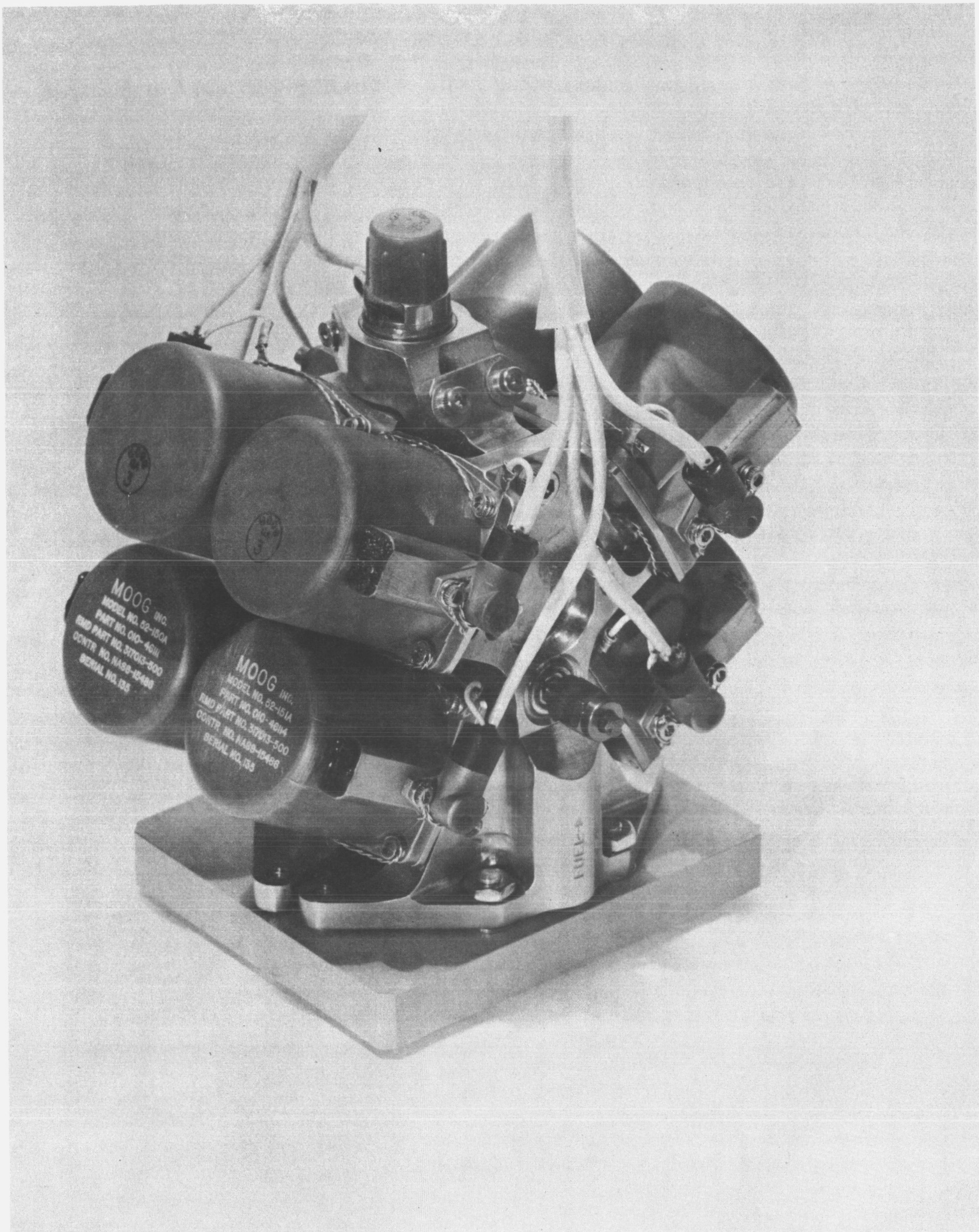
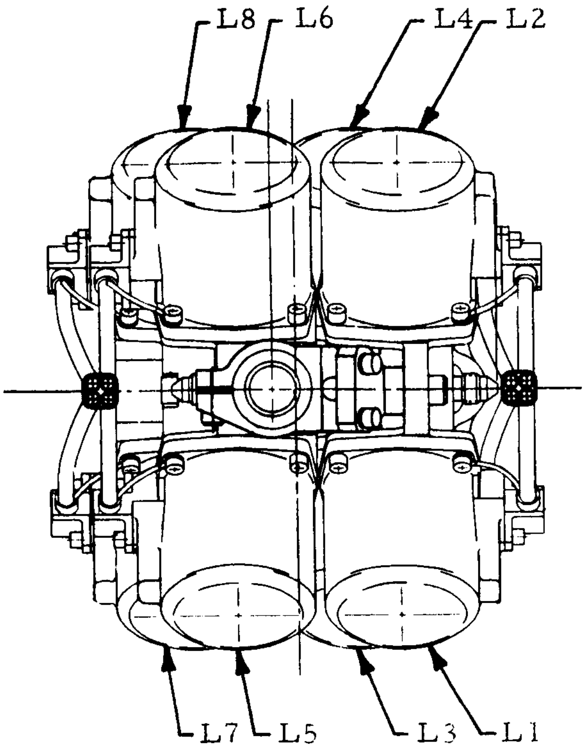
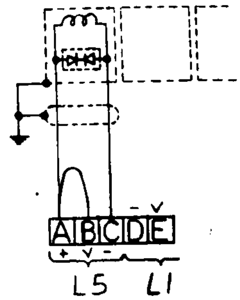
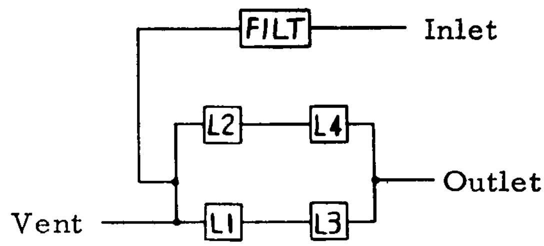


Figure 1.4.2-1. Quadredundant Valve

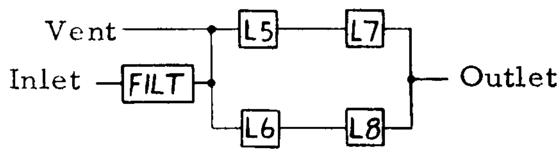




Electrical Schematic

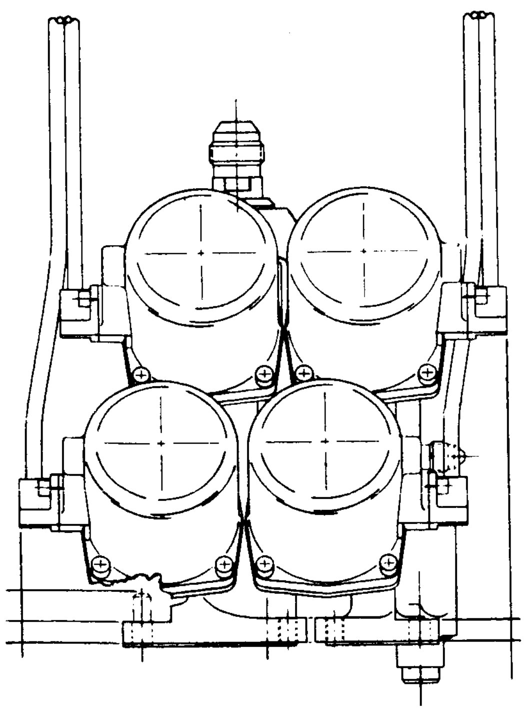


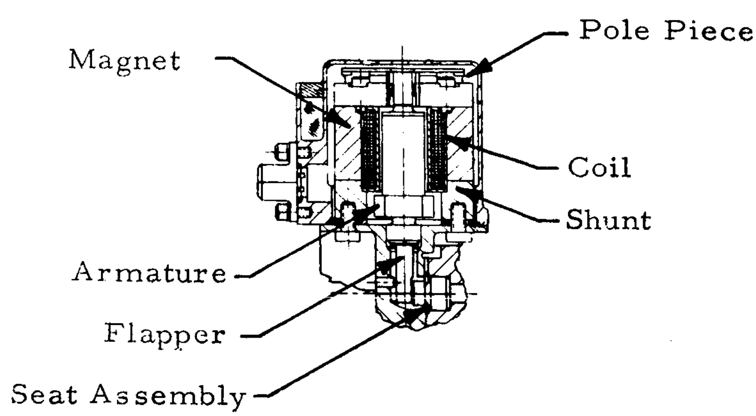
Fuel Valve



Oxidizer Valve

Hydraulic Schematic





Torque Motor (Typ)

Figure 1.4.2-2. Quadredundant Valve Schematic

PART I

BIPROPELLANT VALVE

1.0 SUMMARY

Five (5) bipropellant valve test specimens identified below were subjected to the qualification test program described in Thiokol - RMD Specification EC 20517 (refer to Appendix A for detail).

Thiokol - RMD Part Number	316305-200
Moog Model Number	52-147B
Moog Part Number	010-49029
Thiokol - RMD Serial Numbers	235, 239, 243, 245 and 266

A summary of the performance and environmental test requirements is contained in Table 1.0-I. As noted in this table the test program was a joint effort conducted in part by Moog and Thiokol - RMD. One test speciment (S/N 266) was subjected sequentially to non-operating vibration, operating vibration shock and acceleration as part of the C-1 Engine testing reported in Thiokol - RMD Final Report 6203-Q1. The ~~bi~~propellant valve qualification test program was implemented by the following documents contained in Volume II of this report.

Moog Qualification Test Procedure, Report No. MR 1144, (Revision B Appendix B, Part I - Volume II)

Thiokol - RMD Specification 1426 - Propellant Valve Electrical Interference Test (Appendix C Part I - Volume II)

Thiokol - RMD Specification 1425 - Propellant Valve Propellant Compatibility Tests (Appendix D, Part I - Volume II)

Thiokol - RMD Specification 1433 - Propellant Valve Acceleration Tests (Appendix E, Part I - Volume II)

Thiokol - RMD Specification 15169 - Qualification Test Plan For C-1 Engine (Appendix F - Volume II)

TABLE 1.0-I

BIPROPELLANT VALVE QUALIFICATION
TEST PROGRAM MATRIX

Test Plan Reference Volume II	Test Conducted By	TEST (1)	TEST SPECIMEN 235	239	243	245	266
App. A.	Moog	Acceptance (4.5)	1	1	1	1	1
App. B. Part I	RMD	Temperature (4.7.17)		2			
App. F	RMD	Non-Operating Vibration (4.7.18.1)					2
App. F	RMD	Operating Vibration (4.7.18.2)					3
App. E Part I	RMD	Acceleration (4.7.19)					5
App. F	RMD	Shock (4.7.20)					4
App. A	Moog	Handling Shock (4.7.21)		3			
App. A	Moog	Life (4.7.22)		4	2		
App. D Part I	RMD	Fuel Compatibility (4.7.25.1)				2	
App. D. Part I	RMD	Oxidizer Compatibility (4.7.25.2)				3	
App. A	Moog	Vacuum (4.7.24)	S/N 113 development specimen tested at Dayton T. Brown, Bohemia, Long Island, New York for 600 hours. Requirement 360 hours.				
App. C Part I	RMD	Electrical (4.7.13) Interference	2				
App. A	Moog	Final Performance (4.5.2)		5	3		
App. A	Moog	Burst (4.7.15)		6	4		

(1) Paragraph Number from RMD Spec EC20517 (Refer Appendix A) Volume II

The five specimens successfully completed all qualification tests in accordance with the requirements of the valve detail specification EC 20517 summarized in Table 1.0-I. The requirements of the Contract End Item Specification (CP15166) were satisfactorily demonstrated in this qualification test program or as a part of the development testing. Table 1.0-II summarizes the requirements and also identifies the type of tests conducted during the development and the qualification program. The results of the development test program are discussed in Thiokol-RMD Final Technical Report 6203-F1. The results of the qualification test program are discussed briefly in the subsequent sections of this report. A more detailed discussion of these results is contained in Appendices of Volume II. A tabular summary of the appendix matter contained in Volume II is presented in Table 1.0-III.

TEST (1)

Coil Temperature (3.1.

Operating (3.2.2.1 &
3.2.3.1.2 & 3.2.3.1.3)

Vibration (3.1.2.5.3.1.
3.1.2.5.3.2)

Acceleration
(3.1.2.5.3.1.3 & 3.1.2.

Shock (3.1.2.5.3.2.3)

Sand & Dust (3.1.2.5.2

Salt Spray (3.1.2.5.2.5

Rain (3.1.2.5.2.2)

Fungus (3.1.2.5.2.4)

Propellant Compatibilit

Maximum Temperature

AC-Field Test (3.3.1.4.

Pressure Spike (3.1.1.

Vacuum (3.1.2.5.3.2.5

Burst (3.3.1.2.1)

Cycle Life (3.1.2.2.2.1

Engine Firings (3.1.2.2

Radio Interference (3.3

Handling Shock (3.1.2.3

(1) Paragraph refe

P 11

TABLE 1.0-II

BIPROPELLANT VALVE CONFORMANCE TO

CEI SPECIFICATION 15166 REQUIREMENTS

	PURPOSE	No. of Samples Tested Development	No. of Samples Tested Qualification
2.2.1)	Determine Coil Temperature during MSDC	2	1
	Determine Performance Characteristics over Rated and Operating Range of Temperatures, Pressure and Voltage	4	--
2 &	Verify Design Integrity	4	1
5.3.2.2)	Verify Design Integrity	2	1
	Verify Design Integrity	2	1
.6)	Verify Design Integrity	2	--
	Verify Design Integrity	2	--
	Verify Design Integrity	2	--
	Verify Design Integrity	2	--
y (3.2.3.1)	Verify Design Integrity	2	1
(3.1.2.2.2.1)	Verify Design Integrity	1	--
1.14)	Verify Design Integrity	1	--
5)	Verify Design Integrity	2	--
	Verify Design Integrity	1	--
	Verify Design Integrity	3	2
	Demonstrate Valve Life in excess of 50,000 cycles	4	2
.1.1)	Demonstrate Valve Life Engine in excess of 30,000	~ 12	--
1.4.1.14)	Verify Design Integrity and Performance	2	1
.1.3)	Verify Design Integrity	--	1

renced from CEI Specification 15166

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Appendix	Reference Number	
A	Specification EC20517 - Thiokol-RMD	Valve, Bipropellant Pulse Modulated
B-1	MR 1144 - Moog, Inc.	Bipropellant Valve (
B-II	MR 1175 - Moog, Inc.	Bipropellant Valve (
C-1	Specification 1426 - Thiokol-RMD	Propellant Valve El
C-II	E-1256 - General Precision, Inc.	Environmental Test
D-I	Specification 1425 - Thiokol-RMD	Propellant Compatib
D-II	Compatibility Test Report - Thiokol-RMD	Propellant Compatib
E-I	Specification 1433 - Thiokol-RMD	Acceleration Test
E-II	CDL-1690 - Thiokol-RMD	Valve Qualification, Bipropellant Valve,
F	Specification 15169 - Thiokol-RMD	Qualification Test F
G	M602-8304 - Associated Test Laboratory	Vibration Test (Non
H	M599-8308 - Associated Test Laboratory	Vibration Test (Ope
I	M594-8312 - Associated Test Laboratory	Shock Test

TABLE 1.0-III

SUMMARY OF APPENDICES CONTAINED IN VOLUME II

Title	Description
, Electrical, Torque Motor Operated,	Specifies detail requirements for bipropellant valves
Qualification Test Procedure	Defines test procedure on bipropellant valves S/N 235, 239, 243, 245 and 266 specimens
Qualification Test Report	Presents results of tests of bipropellant valves, S/N 239 and 243
ectrical Interference Test	Defines test procedure for bipropellant and quadredundant valves
Report, Valve S/N 235	Presents results of tests on bipropellant valve S/N 235
bility Test	Defines test procedure for bipropellant and quadredundant valves
bility Test, Valve S/N 245	Presents results of tests of bipropellant valve, S/N 245
	Defines test procedure for bipropellant and quad-redundant valves
Acceleration Testing of one P/N 316305-200, S/N 266	Presents results of tests of bipropellant valve, S/N 266
lan for C-1 Engine	Defines detail vibration and shock requirements for C-1 Engine Assemblies. (Appendices D, E, F and G are not included)
-Operating)	Presents results of tests of bipropellant valve, S/N 266 (Engine S/N 761)
rating)	Presents results of tests of bipropellant valve, S/N 266 (Engine S/N 761)
	Presents results of tests of bipropellant valve, S/N 266 (Engine S/N 761)

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Appendix	Reference Number	
J	MR 1152 - Moog, Inc.	Acceptance Test Dat Assembly
K	Specification EC20518 - Thiokol-RMD	Quadredundant Valve
L-I	MR 1167 - Moog, Inc.	Quadredundant Valve
L-II	MR 1207 - Moog, Inc.	Quadredundant Valve
M	E-1256 - General Precision, Inc.	Environmental Test
N	Compatibility Test Report - Thiokol-RMD	Propellant Compatib (P/N 317013-500, S/
O	CDL 1691 - Thiokol-RMD	Valve Qualification Quadredundant Valve
P-I	M606-8303 - Associated Test Laboratory	Vibration Testing (N
P-II	M601-8306 - Associated Test Laboratory	Vibration Testing (N
P-III	Memorandum - Thiokol-RMD	Prequalification of F Configuration
P-IV	Report - Thiokol-RMD	Disassembly of S/N RES 760
Q-I	M597-8307 - Associated Test Laboratory	Vibration Testing (C

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TABLE 1.0-III

SUMMARY OF APPENDICES CONTAINED IN VOLUME II

Title	Description
a for Bipropellant Control Valve	Presents results of tests of bipropellant valves, S/N 235, 239, 243, 245 and 266.
e Assembly	Specifies detail requirements for quadredundant valves
e Qualification Test Procedure	Defines test procedure for quadredundant valves, S/N 123, 125, 126, 127, 128, 129 and 130 specimens
e Qualification Test Report	Presents results of tests of quadredundant valves, S/N 125, 126, 127, 129 and 130
Report	Presents results of tests of quadredundant valve S/N 128
ility Test Quadredundant Valve 'N 128)	Presents results of tests of quadredundant valve S/N 128
Acceleration Testing of one e P/N 317013-500, S/N 123	Presents results of tests of quadredundant valve, S/N 123
on-Operating)	Presents results of tests of quadredundant valve S/N 130 (Engine S/N 760)
on-Operating)	Presents results of tests of quadredundant valve S/N 129 (Engine S/N 765)
RES 765 Quadredundant Valve	Presents results of tests of quadredundant valve S/N 129
130 Quadredundant Valve From	Presents results of tests of quadredundant valve S/N 130
perating)	Presents results of tests of quadredundant valve S/N 130 (Engine S/N 760)

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Appendix	Reference Number	
Q-II	M600-8310 - Associated Test Laboratory	Vibration Testing (
R	M589-8311 - Associated Test Laboratory	Shock Test
S	MR 1117 - Moog, Inc.	Acceptance Test Da

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TABLE 1.0-III

SUMMARY OF APPENDICES CONTAINED IN VOLUME II

Title	Description
Operating)	Presents results of tests of quadredundant valve S/N 129 (Engine S/N 765)
	Presents results of tests of quadredundant valve S/N 130 (Engine S/N 760)
ta	Presents results of tests of quadredundant valves S/N 123, 125, 126, 127, 128, 129 and 130

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2.0 QUALIFICATION TEST PROGRAM

The bipropellant valve qualification test program was conducted using five test specimens. Each of the specimens was subjected to a series of tests as shown in Table 1.0-I in the Introduction. The subsequent sections of this report will discuss each test and briefly recap the test results. Reference should be made to Table 1.0-III for supporting appendix matter. The applicable paragraph of Specification EC 20517 is also parenthetically noted following each test heading

2.1 ACCEPTANCE (4.5)

Each test specimen was acceptance tested prior to being subjected to the qualification tests. These tests were conducted to assure that performance and operational characteristics of the valves were in compliance with the design requirements of Contract End Item Detail Specification CP 15166. The tests comprised the following:

Examination of Product - to insure conformance of each valve with the applicable drawings.

Proof Pressure - to insure structural integrity of valve.

Electrical Resistance - to insure coil and insulation electrical resistances comply with design requirements.

Dielectric Strength - to demonstrate the electrical integrity of the electrical circuit from the connector to the valve case.

Response - to demonstrate that opening and closing times comply with design requirements.

Functional - to demonstrate operation of the valve at minimum emergency voltage.

Flow - to insure compliance with design pressure drop requirements

External Leakage - to insure weld integrity of the valve.

Internal Leakage - to insure seat integrity of the valve.

Reverse Leakage - to insure seat integrity in the reverse direction to permit system vacuum loading.

The results of the acceptance tests are summarized in Table 2.1-I. All test specimens successfully passed the requirements of this test. Further discussion is contained in Appendix J, Volume II.

TABLE 2.1-I

ACCEPTANCE TEST DATA

Test	Requirement		Specimen S/N 235	239	243	245	266
Dielectric Strength	.050 ma. max	Pins to Body	.006	.011	.009	.010	.006
		Between Coils	.008	.010	.001	.000	.001
Insulation Resistance	100 meg. ohms min.	Pins to Body	2,000	8,000	4,000	30,000	3000
		Between Coils	100,000	40,000	15,000	170,000	15,000
Coil Resistance	Primary	15 ± 1.5 ohm	14.85	14.77	14.78	14.89	14.84
	Secondary	30 ± 3.0 ohm	28.64	28.51	28.76	28.68	28.71
Pressure Drop	Oxidizer Side	32 ± 3 psi	31.0	32.75	31.5	30.2	31.5
	Fuel Side	25 ± 3 psi	25.0	25.5	26.9	26.7	25.2
Pull-In Voltage	Primary	≤16 vdc	8.9	10.4	10.9	7.3*	7.9*
	Secondary	≤16 vdc	9.8	12.1	12.6	11.6*	12.8*
Drop-Out Voltage	Primary	≥1.0 vdc	2.2	1.95	1.38	2.3*	2.1*
	Secondary	≥1.0 vdc	3.7	3.30	2.3	3.5*	3.3*
Opening Response	Primary	≤9.0 msec	5.7	7.0	4.8	6.8*	7.0*
	Secondary	≤ 50 msec	17.0	44.5	31.0	23.0	36.0
Closing Response	Primary	≤5.0 msec	2.6	2.8	2.8	2.8*	2.6*
	Secondary	≤5.0 msec	2.2	2.4	2.4	2.4	2.2
Internal Leakage	5 cc/hr	Fuel	1.0	1.0	2.5	0	2.0
		Oxidizer	3.5	2.5	2.5	0	0

*Test Pressures Revised to comply with Revision "B" to the CEI CP15166.

2.2 TEMPERATURE EXTREMES (4.7.17)

The purpose of this test is to demonstrate valve performance at the combined most severe operating conditions. The following criteria were established for this series of tests which were conducted at maximum (+180F) and minimum (+12F) ambient temperatures.

- Response at the maximum rated pressure (212 psig) with the minimum rated voltage of 22 vdc. Testing at +180F uses "hot amps" which simulates a condition of valve operation at minimum rated voltage immediately after a thermal soak due to a 500 second "on" time at the nominal rated voltage (28 vdc). The value of "hot amps" is determined for each coil by energizing the coils individually with 28 vdc for 500 seconds. The voltage is then reduced to 22 vdc and the coil current measured.
- Operation (pull-in) at the maximum operating pressure (325 psig) with the minimum operating voltage (20 vdc).
- Operation (drop-out) at the minimum operating pressure (166 psig) with the drop-out voltage (1 vdc).

The results of the temperature tests are summarized in Table 2.2-I. Test specimen S/N 239 successfully passed the requirements of this test. Further discussion is contained in Appendix B, Part II, Volume II.

2.3 NON-OPERATING VIBRATION (4.7.18.1)

The purpose of this test is to demonstrate valve capabilities under a launch vehicle boost vibration environment. Vibration Testing was performed dry and unpressurized on valve S/N 266 (assembled as part of C-1 Engine Assembly (S/N 761). The vibration requirements are indicated in Figure 2.3-1 and include sinusoidal and random spectrums. Testing was accomplished with the valve attached to the engine to ensure that the valve was exposed to actual vibration including engine amplification (see Figure 2.3-2). Interaxis performance testing shown in Table 2.3-I was conducted at the completion of each sinusoidal and random vibration axes. Test specimen valve S/N 266 successfully passed the requirements of this test. Further discussion is contained in Appendix G, Volume II.

2.4 OPERATING VIBRATION (4.7.18.2)

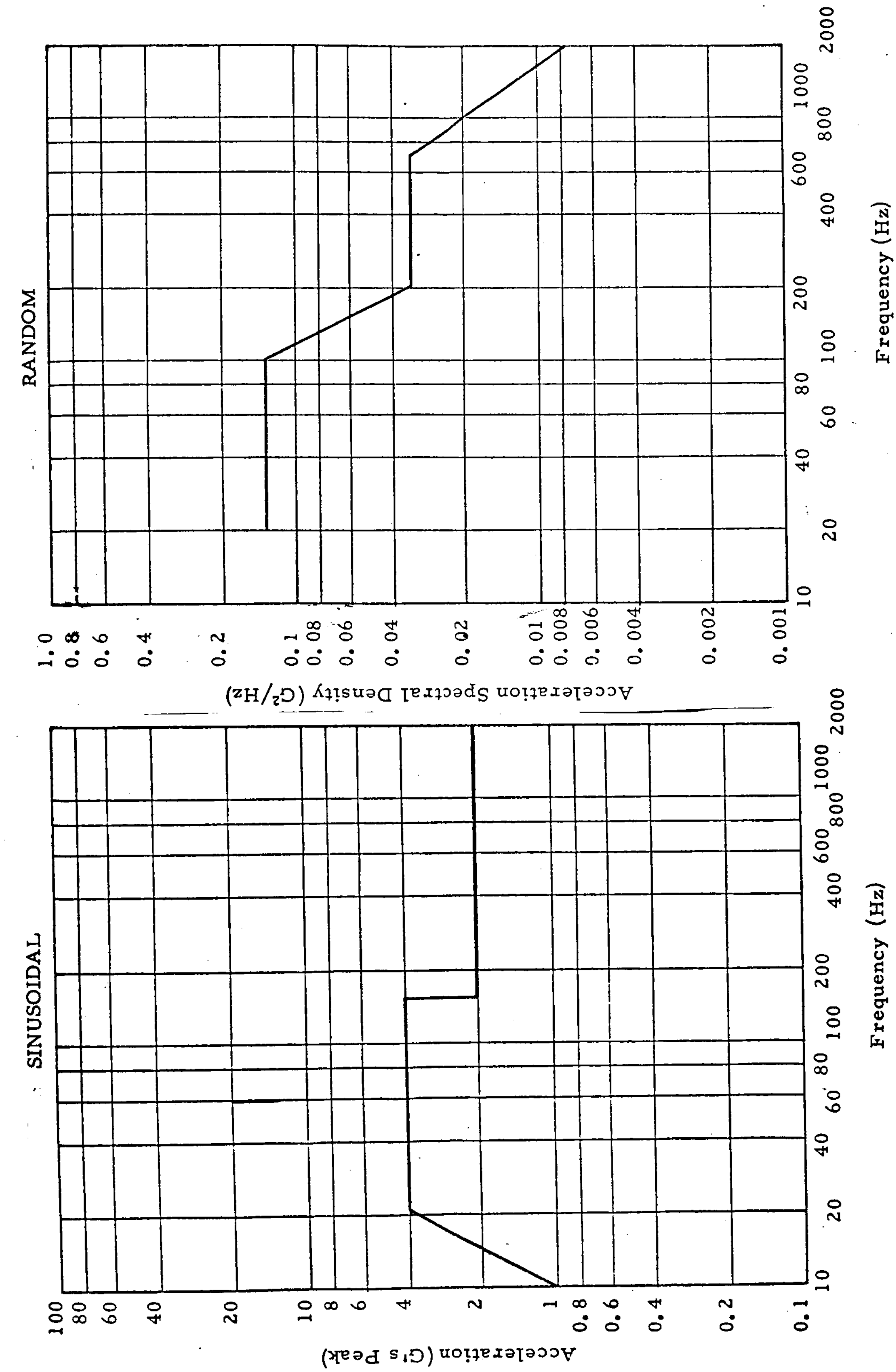
The purpose of this test is to demonstrate valve capabilities under a spacecraft vibration environment. Vibration testing was performed wet and pressurized on valve S/N 266, assembled as part of a C-1 Engine assembly (S/N 761). The vibration requirements are indicated in Figure 2.4-1 and include sinusoidal and random spectrums. Testing was accomplished with the valve attached to the engine to ensure that the valve was exposed to actual vibration including engine amplification. Refer to Table 2.4-I. Test specimen valve S/N 266 successfully passed the requirements of this test. Further discussion is contained in Appendix H, Volume II.

TABLE 2.2-I

TEMPERATURE TEST

Item	Condition* P_{inlet} (psig)	Volts (vdc)	Hot Amps	Temp (°F)	Requirement		Demonstration
o Response							
Primary Coil	310	22	Yes	+180	Opening Time	9 msec	7.7
					Closing Time	5 msec	2.6
			No	+12	Opening Time	9 msec	6.6
					Closing Time	5 msec	3.4
Secondary Coil	360	22	Yes	+180	Opening Time	50 msec	35.5
					Closing Time	5 msec	2.4
			No	+12	Opening Time	50 msec	14.0
					Closing Time	5 msec	3.0
o Operation							
Pull-In							
Primary Coil	360	--	---	+180	Pull-In Voltage	20 vdc	10.4
Primary Coil		--	---	+12			6.88
Secondary Coil		--	---	+180			15.7
Secondary Coil	360	--	---	+12			10.9
Drop-Out							
Primary Coil	166	--	---	+180	Drop-Out Voltage	10 vdc	2.83
Primary Coil		--	---	+12			1.59
Secondary Coil		--	---	+180			3.75
Secondary Coil	166	--	---	+12			2.72

* Pressure requirements were subsequently revised below the test value.



5 minutes/axis

Sweep at 1 octave/minute

Vibration Inputs to Engine Mounting Flange as defined in RMD Spec 15169

Figure 2.3-1. Non-Operating (Unpressurized) Vibration

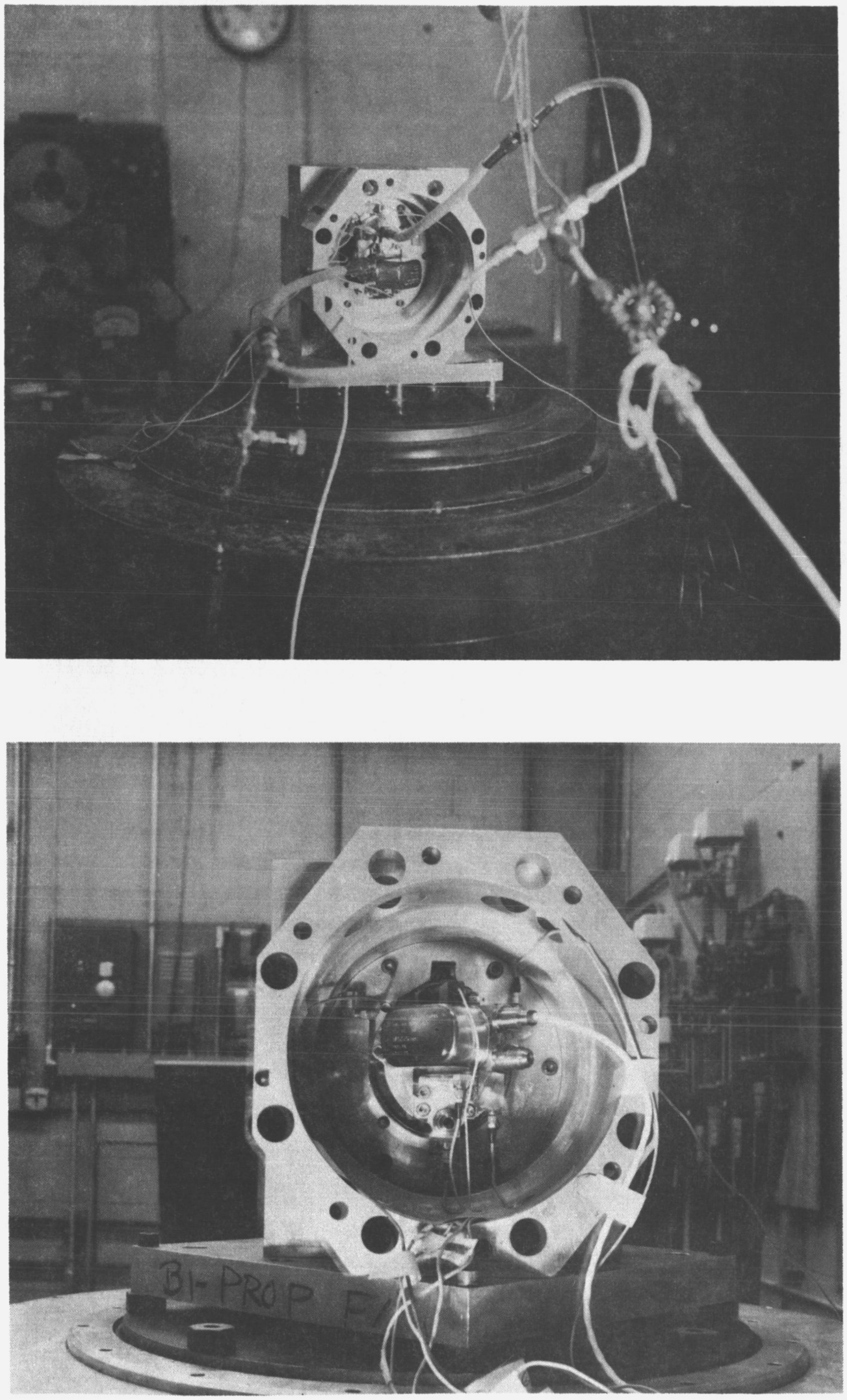
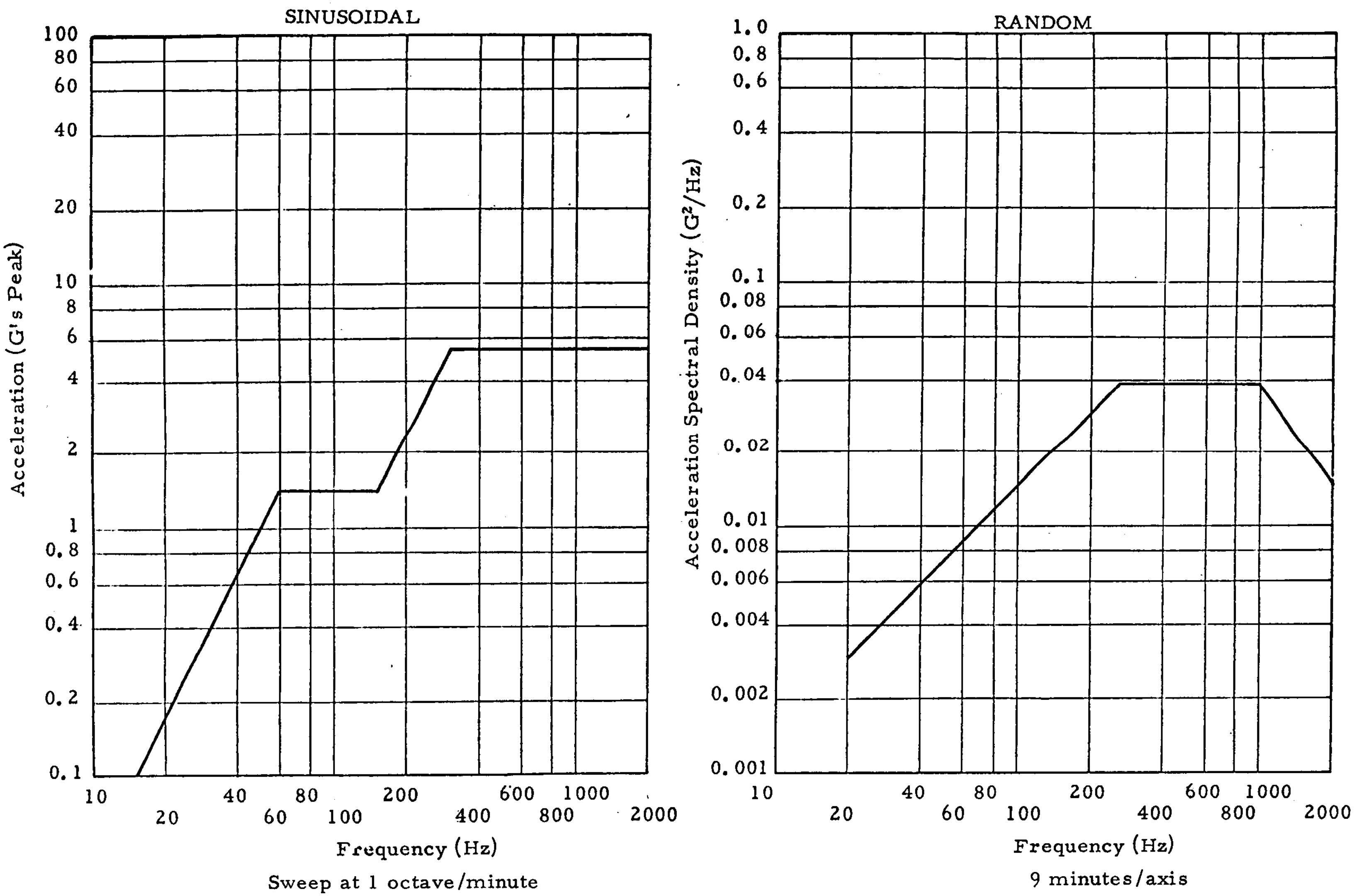


Figure 2.3-2. Bipropellant Valve Mounted in Valve-Engine Vibration Fixture

TABLE 2.3-I

NON-OPERATING VIBRATION

After Completion Of	Prior To Vib	AXIS A		AXIS B		AXIS C	
		Sine	Random	Sine	Random	Sine	Random
Functional Test							
Primary Volts (Pull-In) Amps	3.4 .170	3.3 .158	2.8 .160	3.5 .180	3.3 .168	3.3 .160	3.2 .165
Primary Volts (Drop-Out) Amps	2.5 .070	2.2 .070		2.3 .076	2.2 .072	2.3 .058	2.2 .070
Secondary Volts (Pull-In) Amps	3.3 .166	4.6 .136	4.5 .140	4.5 .140	4.7 .137	4.6 .134	4.6 .136
Secondary Volts (Drop-Out) Amps	2.7 .080	2.0 .025		2.0 .027	2.3 .058	2.3 .058	2.2 .032
Leakage Test							
-- Internal-- 50 psig Fuel Oxidizer	0 0	0 0	0 0	0 0	0 0	0 0	0 0
325 psig Fuel Oxidizer	0 0	0 0	0 0	0 0	0 0	0 0	0 0
--Reverse-- 20 psig Fuel Oxidizer	0 0	0 0	0 0	0 0	0 0	0 0	0 0



Vibration Inputs to Engine Mounting Flange as defined in RMD Spec 15169.

Figure 2.4-1. Operating (Pressurized) Vibration

TABLE 2.4-I

OPERATING VIBRATION TEST

After Completion Of	AXIS A	AXIS B	AXIS C
Functional Test			
Primary Volts	3.3	3.6	3.2
(Pull-In) Amps	.168	.152	.154
Primary Volts	1.8	2.9	2.3
(Drop-Out) Amps	.094	.08	.104
Secondary Volts	5.2	5.2	4.3
(Pull-In) Amps	.145	.140	.176
Secondary Volts	2.6	2.7	2.4
(Drop-Out) Amps	.072	.060	.081
Leakage Test			
--Internal--			
50 psig Fuel	0	0	0
Oxidizer	0	0	0
325 psig Fuel	0	0	0
Oxidizer	0	0	0
--Reverse--			
20 psig Fuel	0	0	0
Oxidizer	0	0	0

2.5 ACCELERATION (4.7.19)

The purpose of this test is to demonstrate valve capabilities under both launch vehicle boost and spacecraft operating environments. Acceleration testing was performed on valve S/N 266, assembled as part of C-1 Engines Assembly (S/N 761-1). The engine assembly was mounted in a fixture simulating its normal mounting configuration and mounted on the end of the rotating arm in a centrifugal testing machine. Testing was accomplished at the following levels:

- Pressurized, Non-operating, 20 g's for 6 minutes.
- Pressurized, Operating, 20 g's for 2 minutes.

Testing was performed in each direction in each of three mutually perpendicular axes. The results of the acceleration tests are summarized in Table 2.5-I. Test specimen S/N 266 successfully passed the requirements of this test. Further discussion is contained in Appendix E, Part II, Volume II.

2.6 SHOCK (4.7.20)

The purpose of this test is to demonstrate valve capabilities under launch vehicle stage separation. Shock testing was performed on valve S/N 266, assembled as part of C-1 Engine assembly (S/N 761-1). The engine assembly was mounted in a fixture and secured to the platform of a shock machine (See Figure 2.6-1). It was subjected to twenty "g" peaks, half sine wave shock pulses of ten milliseconds duration. The shocks were applied three times in both directions in each of three axes for a total of eighteen shock impacts. The results of the shock tests are summarized in Table 2.6-I Test specimen valve S/N 266 successfully passed the requirements of this test. Further discussion is contained in Appendix I, Volume II.

2.7 HANDLING SHOCK (4.7.21)

The purpose of this test is to demonstrate valve capabilities under normal handling abuse prior to being assembled to an engine. The handling shock tests (four 45 degree edge drops and one one-inch drop on each valve face on a solid hardwood bench top) was performed on valve S/N 239. The results of the handling shock test are summarized in Table 2.7-I. Test specimen S/N 239 successfully passed the requirements of this test. Further discussion is contained in Appendix B, Part II, Volume II.

TABLE 2.5-I

ACCELERATION TESTS

TEST	REQUIREMENT	TEST RESULTS Pre Accl	Acceleration Axis A-	A+	B-	B+	C-	C+
Opening Response	Primary } At Non-Rated Conditions	---	4.0	6.0	6.5	5.0	4.0	6.0
Closing Response	Primary } At Non-Rated Conditions	---	4.0	4.0	5.0	5.0	4.0	4.0
Internal Leakage*	< 200 cc/hr (Gaseous)							
	Fuel	None	---	None	---	None	---	None
	Oxidizer	None	---	None	---	None	---	None
External Leakage*	$<10^{-4}$ sccps He	None	---	---	---	---	---	None
Internal Leakage	Zero (Liquid)							
	Fuel	---	None	None	None	None	None	None
	Oxidizer	---	None	None	None	None	None	None

*After Test Completion

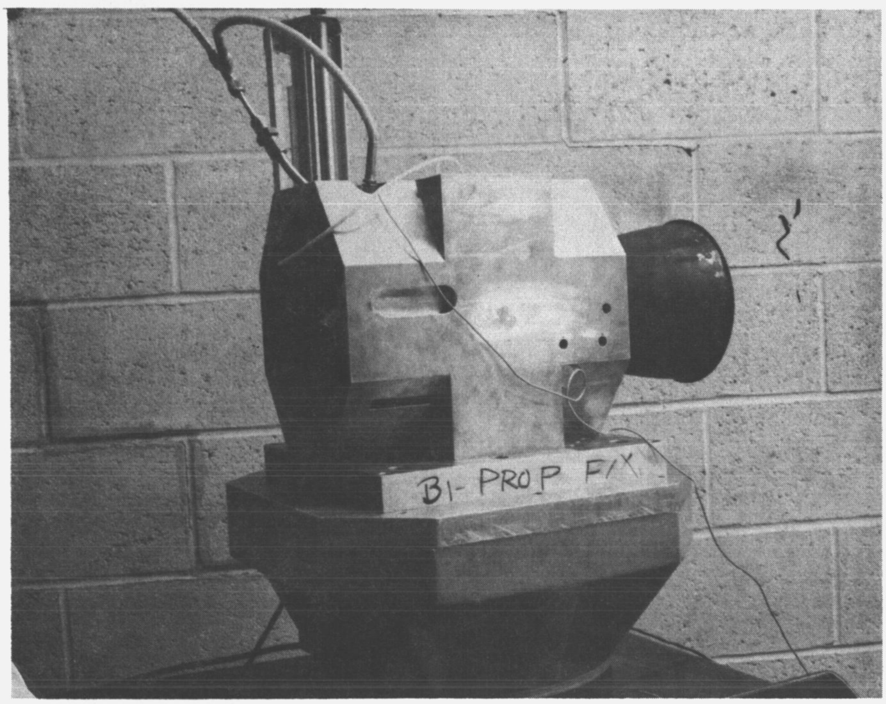


Figure 2.6-1. Valve S/N 266 (Engine 761-1) Shock Testing Setup

TABLE 2.6-I

SHOCK TEST

After Completion	AXIS A	AXIS B	AXIS C
Functional Test			
Primary Volts	3.3	3.5	3.0
(Pull-In) Amps	.160	.156	.168
Primary Volts	2.6	2.6	2.6
(Drop-Out) Amps	.096	.089	.082
Secondary Volts	5.3	5.3	5.1
(Pull-In) Amps	.140	.150	.140
Secondary Volts	3.0	3.2	3.0
(Drop-Out) Amps	.070	.074	.080
Leakge Test			
--Internal--			
50 psig Fuel	0	0	0
Oxidizer	0	0	0
325 psig Fuel	0	0	0
Oxidizer	0	0	0
--Reverse--			
20 psig Fuel	0	0	0
Oxidizer	0	0	0

TABLE 2.7-I

HANDLING SHOCK TEST RESULTS

Test	Requirement		Pre Shock Test	Post Shock Test
Coil Resistance	Primary	15 ± 1.5 ohm	15.08	15.04
	Secondary	30 ± 3.0 ohm	28.96	28.94
Pressure Drop	Oxidizer Side	32 ± 3 psi	32.25	32.25
	Fuel Side	25 ± 3 psi	25.75	25.25
Pull-In Voltage	Primary	≤16 vdc	8.34	7.78
	Secondary	≤16 vdc	13.6	11.7
Drop-Out Voltage	Primary	≥1.0 vdc	2.16	2.07
	Secondary	≥1.0 vdc	3.38	2.85
Opening Response	Primary	≤9.0 msec	8.6	6.4
	Secondary	≤50. msec	34.5	20.5
Closing Response	Primary	≤5.0 msec	3.0	3.0
	Secondary	≤5.0 msec	2.6	2.4
Internal Leakage	<200 cc/hr			
	Fuel		None	None
	Oxidizer		None	None
External Leakage	$< 10^{-4}$ sccps He		None	None

2.8 LIFE TEST (4.7.22)

The purpose of this test is to demonstrate the valve capability in excess of the specification requirement of 50,000 cycles. Life cycling tests were conducted on two valve specimens. The valves were cycled at 10 cycles per second for 50,000 cycles, using the maximum operating pressure (325 psig). Valve performance parameters including response and leakage were measured at 10,000 cycle intervals. The results of the interval performance tests are shown in Table 2.8-I. The two specimens, S/N 239 and 243, successfully passed the requirements of this test. Further discussion is contained in Appendix B, Part II, Volume II.

2.9 PROPELLANT COMPATIBILITY

2.9.1 FUEL COMPATIBILITY (4.7.25.1)

This test was conducted to assure valve compatibility with liquid fuel. The valve was subjected to a spray of liquid fuel maintained at +160F until all surfaces were wet and then allowed to air dry for 24 hours at 80F and ambient humidity. The test specimen, S/N 245 successfully passed the requirements of this test. Further discussion is contained in Appendix D, Part II, Volume II.

2.9.2 OXIDIZER COMPATIBILITY (4.7.25.2)

This test was conducted to assure valve compatibility with liquid and gaseous oxidizer. The tests comprised the following:

- 65F liquid oxidizer spray followed by 24 hours air dry
- One hour exposure to oxidizer vapor followed by 24 hours air dry

The test specimen, S/N 245 successfully passed the requirements of this test. Further discussion is contained in Appendix D. Part II, Volume II.

2.10 VACUUM TEST (4.7.24)

These tests were conducted to assure valve electrical capabilities under a simulated vacuum environment. Vacuum test results from the Development Test Program (valve specimen S/N 113, P/N 316305-100) were declared valid for Qualification Program use.

The primary reasons for this approach were:

- There were no coil potting material changes since the development vacuum test was performed.

TABLE 2.8

TEST	REQUIREMENT		S/N Pre-Life Test	Post 10,000 Cycles	Post 20,000 Cycles
• Coil Resistance	Primary Secondary	15±1.5 ohm 30±3.0 ohm	15.04 28.94	14.98 28.81	14.98 28.73
• Pressure Drop	Oxidizer Side Fuel Side	32±3 psi 25±3 psi	32.25 25.25	32.0 26.25	31.75 26.75
• Pull-In Voltage	Primary Secondary	≤ 16 vdc ≤ 16 vdc	7.78 11.7	7.82 12.3	7.89 12.10
• Drop-Out Voltage	Primary Secondary	≥ 1.0 vdc ≥ 1.0 vdc	2.07 2.85	2.16 3.27	2.21 3.37
• Opening Response	Primary Secondary	≤ 9.0 msec ≤ 50 msec	6.4 20.5	6.2 25.0	6.0 22.5
• Closing Response	Primary Secondary	≤ 5.0 msec ≤ 5.0 msec	3.0 2.4	2.7 2.4	3.0 2.4
• Internal Leakage	< 200 cc/hr	Fuel Oxidizer	None None	None None	None None
• External Leakage	$<10^{-4}$ sccps He		None	None	None

* Test procedure revised to use Drop-Out Switch of Figure F-1 of TCC-RMD Speci

-I LIFE TEST

239			S/N 243					
Post 30,000 Cycles	Post 40,000 Cycles	Post 50,000 Cycles	Pre-Life Test	Post 10,000 Cycles	Post 20,000 Cycles	Post 30,000 Cycles	Post 40,000 Cycles	Post 50,000 Cycles
15.02	15.52	15.16	14.98	14.12	14.98	15.05	14.99	15.14
28.73	29.67	29.03	29.09	29.16	29.15	29.14	29.08	29.38
32.30	30.50	31.00	30.25	30.75	30.00	30.25	31.50	31.50
27.00	26.25	26.50	24.75	24.25	24.75	24.60	24.50	24.75
7.80	8.00	7.58	8.94	7.20	6.94	7.11	6.50	6.31
11.70	11.70	11.60	14.6	11.50	11.1	11.0	10.30	10.10
2.28	2.30	2.38	1.90	>1.0*	>1.0*	>1.0*	>1.0*	>1.0*
3.48	3.60	3.57	2.99	>1.0*	>1.0*	>1.0*	>1.0*	>1.0*
6.2	6.6	6.7	7.0	4.8	4.6	5.0	4.8	5.2
23.5	37.0	25.5	22.0	17.5	18.0	23.0	17.5	18.0
2.8	3.1	3.0	3.0	2.9	3.0	2.8	3.0	3.0
2.4	2.6	2.5	2.4	2.4	2.6	2.4	2.4	2.4
10.2	None	4.0	None	None	None	None	None	7.0
57.6	None	17.4	None	None	None	None	None	None
None	None	None	3.16×10^{-6}	None	None	None	None	None

fication 15169.

FOLDOUT FRAME 2

- The testing was performed with the torque motor cover removed to ensure vacuum exposure of all torque motor parts (coils, magnets, etc.)

- The test was performed for a significant duration (600 hour actual exposure).

The following results were extracted directly from the Moog Bipropellant Valve Development Test Report MR 1145, Paragraph 7.16.

> "Test specimen Serial Number 113 was subjected to the vacuum test at the Dayton T. Brown Testing Laboratories, Bohemia, Long Island, New York. The test was started on April 13, 1966, and completed on May 3, 1966. The test data recorded while the valve was in the vacuum environment, and the results of the post vacuum interval performance test, show no degradation of performance due to the environment.
>
> The valve, with the motor cap removed, was installed in the vacuum chamber and was subjected to 600 hours at a maximum pressure of 10^{-6} mm Hg. Prior to reducing chamber pressure, immediately after reducing chamber pressure, at five day intervals, and during the last hour at reduced pressure, the valve was subjected to the following test sequence. The primary coil of the valve was energized by slowly increasing signal voltage from 0 to 30 vdc. The 30 vdc was maintained for five minutes and was then slowly decreased until the valve closed (de-energized). The energizing (pull-in) and de-energizing (dropout) voltages were recorded. The valve was then cycled 100 times at 1 cps while the coil voltage was varied from 16 to 30 vdc. While the coils were still hot from cycling, the valve was subjected to the dielectric strength test. The values for the pull-in and dropout voltage test and the dielectric strength test are included in Table 2.10-I."

2.11 ELECTRICAL INTERFERENCE (4.7.13)

Test specimen S/N 235 was subjected to electrical interference testing in accordance with MIL-I-6181D. These tests were conducted to

TABLE 2.10-I

VACUUM TEST DATA

MODEL 52-147 SERIAL NUMBER 113

Test	4-13-66	4-14	4-19	4-24	4-29	5-4	5-9	5-9
Coil Resistance (ohms)								
Pins A-B	14.89	14.9	14.9	15.0	14.9	14.7	14.9	15.1
Pins C-D	28.70	28.5	28.5	28.8	28.5	28.2	28.7	29.0
Pull-In Voltage	N_2 at 465 psig							
Primary - volts	8.79	3.00	3.05	3.13	2.82	2.77	2.79	2.46
amps	0.58	0.164	0.132	0.239	0.199	0.185	0.182	0.175
Dropout Voltage	N_2 at 163 psig							
Primary - volts	1.16	1.86	2.52	2.48	2.01	1.99	2.08	1.95
amps	0.073	0.073	0.080	0.075	0.072	0.075	0.073	0.079
Dielectric Strength (a)								
Coils AB-CD	1	1	1	1	1	1	1	1
AB to Ground	1	2.5	1	1	1	4	1.5	1
CD to Ground	1	1.5	1	1	1	2.5	1	1
Ambient Pressure mm/Hg x 10^{-7}	Local Ambient	6	4.5	6	2.5	2.6	1.5	Local Ambient

Note: Pull-in and dropout voltage tests at altitude were conducted with the valve unpressurized. The voltage and current values for pull-in and dropout voltage in the table above are evidently inaccurate because they indicate a large variation in coil resistance during the program which was not substantiated during the coil resistance test. It is suspected that an instrumentation problem existed which was not discovered. However, the inaccuracy of the instrumentation does not invalidate the test.

determine the following:

- the magnitude of radiated interference emanating from the valve during actuation.
- valve susceptibility to radiated interference.
- valve susceptibility to conducted interference.

Radiated interference did not exceed MIL-I-6181D requirements. There was no evidence of valve susceptibility to either radiated or conducted interference. The valve successfully passed the requirements of this test. Further discussion is contained in Appendix C, Part II, Volume II.

2.12 FINAL PERFORMANCE (4.5.2)

The test speciments, S/N 239 and 243, were subjected to a repeat of the original acceptance tests as described in Section 2.1 of this report. Table 2.12-I compares final performance (Post Qualification) and initial performance (Pre-qualification) to specification requirements. Both specimens met all specification requirements before and after the Qualification Test Program. Further discussion is contained in Appendix B, Part II, Volume II.

2.13 BURST (4.7.15)

These tests were conducted to assure valve compliance with the design requirements of Contract End Item Detail Specification CP15166. The two valve specimens, S/N 239 and 243, withstood the burst pressure (2000 psig) for two minutes, therefore successfully passing the requirements of this test. The pressures were then slowly increased until the specimens failed. These pressures were:

S/N 239	8800 psig
S/N 243	9300 psig

Further discussion is contained in Appendix B, Part II, Volume II.

TABLE 2.12-I. FINAL PERFORMANCE

TEST	REQUIREMENT		S/N 239		S/N 243	
			Pre Qual	Post Qual	Pre Qual	Post Qual
• Dielectric Strength	.050 ma. max	Pins to body between coils	$<.001$ $.001$	$<.001$ $<.001$	$<.001$ $<.001$	$<.001$ $.001$
• Insulation Resistance	100 meg. ohms min	Pins to body between coils	>1000 >1000	>1000 >1000	>1000 >1000	>1000 >1000
• Coil Resistance	Primary Secondary	15 ± 1.5 ohm 30 ± 3.0 ohm	14.97 28.68	15.16 29.03	14.98 29.09	15.14 29.38
• Pressure Drop	Oxidizer side Fuel side	$32 + 3$ psi 25 ± 3 psi	30.50 25.25	31.00 26.50	30.25 24.75	31.50 24.75
• Pull-In Voltage	Primary Secondary	≤ 16 vdc ≤ 16 vdc	8.62 13.5	7.58 11.60	8.94 14.6	6.31 10.10
• Drop-Out Voltage	Primary Secondary	≥ 1.0 vdc ≥ 1.0 vdc	2.25 3.57	2.38 3.57	1.90 2.99	>1.0* >1.0*
• Opening Response	Primary Secondary	≤ 9.0 msec ≤ 50 msec	8.8 20.0	6.7 25.5	7.9 22.0	5.2 18.0
• Closing Response	Primary Secondary	≤ 5.0 msec ≤ 5.0 msec	3.2 3.0	3.0 2.5	3.0 2.4	3.0 2.4
• Internal Leakage	<200 cc/hr	Fuel Oxidizer	None None	4.0 17.4	None None	7.0 2.5
• External Leakage	$<10^{-4}$ sccps He		7.32×10^{-6}	None	3.16×10^{-6}	None

* Test procedure revised to use Drop-Out Switch of Figure F-1 of TCC-RMD Specification 15169

PART II

QUADREDUNDANT VALVE

1.0 SUMMARY

Seven (7) quadredundant valve test specimens identified below were subjected to the qualification test program described in Thiokol-RMD Specification EC 20518 (refer to Appendix K, Volume II for detail).

Thiokol-RMD Part Number	317013-500
Moog Model Number	50-304
Moog Part Number	010-46152-1
Thiokol-RMD Serial Numbers	123, 125, 126, 127, 128, 129, and 130

A summary of the performance and environmental test requirements is contained in Table 1.0-I. As noted in this table, the test program was a joint effort conducted in part by Moog and Thiokol-RMD. Two test specimens (S/N 129 and 130) were subjected sequentially to non-operating vibration, operating vibration shock and acceleration as part of the C-1 Engine testing reported in Thiokol-RMD Final Report 6203-Q1. During engine qualification this test sequence was modified to operating vibration and and shock only. The quadredundant valve qualification test program was implemented by the following documents contained in Volume II of this report.

Moog Qualification Test Procedure, Report No. MR 1167, (Appendix K, Part I, Volume II)

Thiokol-RMD Specification 1426 - Propellant Valve Electrical Interference Test (Appendix C, Part I, Volume II)

Thiokol-RMD Specification 1425 - Propellant Valve Propellant Compatibility Tests (Appendix D, Part I, Volume II)

Thiokol-RMD Specification 1433 - Propellant Valve Acceleration Tests (Appendix E, Part I, Volume II)

Thiokol-RMD Specification 15169 - Qualification Test Plan For C-1 Engine (Appendix F, Volume II)

TABLE 1.0-I

QUADREDUNDANT VALVE QUALIFICATION TEST PROGRAM MATRIX

Test Plan Reference Volume II	Test Conducted By	Test[1]	Test Specimen 123	125	126	127	128	129	130
App. K	Moog	Acceptance (4.5)	1	1	1	1	1	1	1
App. L Part I	Moog	Temperature (4.7.17)						2	
App. F	RMD	Non-Operating Vibration (4.7.18.1)						3	2
App. F	RMD	Operating Vibration (4.7.18.2)						4	3
App. E Part I	RMD	Acceleration (4.7.19)	2						
App. F	RMD	Shock (4.7.20)							4
App. K	Moog	Handling Shock (4.7.21)				2			
App. K	Moog	Life (4.7.22)			2	3			
App. D Part I	RMD	Fuel Compatibility (4.7.24.1)					2		
App. D Part I	RMD	Oxidizer Compatibility (4.7.24.2)					3		
App. K	Moog	Vacuum (4.7.23)							5
App. C Part I	RMD	Electrical Interference (4.7.13)					4		
App. K	Moog	Final Performance (4.5.2)				4		5	
App. K	Moog	Burst (4.7.15)			2				

(1) Paragraph Number from RMD Specification EC20518
(Refer Appendix K, Volume II)

The development of the quadredundant valve was accomplished under pressurized, non-operating vibration. This requirement was changed late in the C-1 Program to unpressurized, non-operating vibration which the valve did not successfully demonstrate. The timing of this specification revision did not permit redesign of the valve to enable it to sustain this unpressurized vibration test. Therefore, the C-1 quadredundant valve engine was not subjected to this type of testing. However, an extensive redesign and test program described in Thiokol-RMD Final Technical Report 6203-F1 has been initiated by Moog to resolve this valve deficiency. The valve redesign and demonstration test test program consists basically of:

- Vibration testing to define failure mode and problem area in valve.
- Valve redesign to eliminate the failure.
- Proof of principle test of one sample.
- Demonstration testing of five modified valves at the qualification vibration test levels.

The results of this testing will be issued as an addendum to Thiokol-RMD Report 6203-Q1.

The requirements of the CEI were satisfactorily demonstrated in this qualification test program or as a part of the development testing. Table 1.0-II summarizes the significant environmental conditions and also identifies the type of tests conducted during the development and the qualification program. The results of the development test program are discussed in Thiokol-RMD Report 6203-F1. The results of the qualification test program are discussed briefly in the subsequent sections of this report. A more detailed discussion of these results is contained in Appendices of Volume II. A tabular summary of the appendix matter contained in Volume II is presented in Table 1.0-III.

TABLE 1.0-II

QUADREDUNDANT VALVE CONFORMANCE TO

CEI SPECIFICATION 15166 REQUIREMENTS

TEST [1]	PURPOSE	No. of Samples Tested Development	No. of Samples Tested Qualification
Coil Temperature (3.1.2.2.2.1)	Demonstrate Coil Temperature $<$ 500F during MSDC	2	1
Operating (3.2.2.1 & 3.2.3.1.2 & 3.2.3.1.3)	Determine Valve Performance over Rated and Operating Range of Voltage, Pressure and Temperature	3	--
Vibration (3.1.2.5.3.1.2 & 3.1.2.5.3.2)	Verify Design Integrity	3	2
Electrical Interference (3.3.1.4.1.14)	Verify Design Integrity	1	1
Acceleration (3.1.2.5.3.1.3 & 3.1.2.5.3.2.2)	Verify Design Integrity	--	1
Sand and Dust (3.1.2.5.2.6)	Verify Design Integrity	1	--
Shock (3.1.2.5.3.2.3)	Verify Design Integrity	--	1
Salt Spray (3.1.2.5.2.5)	Verify Design Integrity	1	--
Handling Shock (3.1.2.5.1.3)	Verify Design Integrity	--	1
Pressure Spike (3.1.1.5)	Verify Design Integrity	1	--
Vacuum (3.1.2.5.3.2.5)	Demonstrate Valve Life	--	1
Cycle Life (3.1.2.2.2.1)	Demonstrate Valve Life in excess of 10,000 cycles	3	2
Propellant Compatibility (3.2.3.1)	Verify Design Integrity	1	1
Burst (3.3.1.2.1)	Demonstrate Burst Pressure in excess of 1150 psig	2	1
Engine Firings (3.1.2.2.1.1)	Demonstrate Valve Life in excess of 10,000 cycles	4	--

(1) Paragraph referenced from CEI Specification 15166

2.0 QUALIFICATION TEST PROGRAM

The quadredundant valve qualification test program was conducted using seven (7) test specimens. Each of the specimens was subjected to a series of tests as shown in Table 1.0-I (Part II). The subsequent sections of this report will discuss each test and briefly recap the test results. Reference should be made to Table 1.0-III (Part I) for supporting appendix matter. The applicable paragraph of Specification EC 20518 is also parenthetically noted following each test heading.

2.1 ACCEPTANCE (4.5)

Each test specimen was acceptance tested prior to being subjected to the qualification tests. These tests were conducted to assure that performance and operational characteristics of the valves were in compliance with the design requirements of Contract End Item Detail Specification CP 15166. The tests comprised the following:

Examination of Product - to insure conformance of each valve with the applicable drawings.

Proof Pressure - to insure structural integrity of valve.

Electrical Resistance - to insure coil and insulation electrical resistances comply with design requirements.

Dielectric Strength - to demonstrate the electrical integrity of the electrical circuit from the connector to the valve case.

Response - to demonstrate that opening and closing times comply with design requirements.

Functional - to demonstrate operation of the valve at minimum emergence voltage.

Flow - to insure compliance with design pressure drop requirements.

External Leakage - to insure weld integrity of the valve.

Internal Leakage - to insure seat integrity of the valve.

Reverse Leakage - to insure seat integrity in the reverse direction to permit system vacuum loading.

The results of the acceptance tests are summarized in Table 2.1-I. All test specimens successfully passed the requirements of this test. Further discussion is contained in Appendix S, Volume II.

2.2 TEMPERATURE EXTREMES (4.7.17)

The purpose of this test is to demonstrate valve performance at the combined most severe operating conditions. The following criteria were established for this series of tests which were conducted at maximum (+180F) and minimum (+12F) ambient temperatures.

- Response at the maximum rated pressure (212 psig) with the minimum rated voltage of 22 vdc. Testing at +180F uses "hot amps" which simulates a condition of valve operation at minimum rated voltage immediately after a thermal soak due to a 500 second "on" time at the nominal rated voltage (26 vdc). The value of "hot amps" is determined for each coil by energizing the coils individually with 26 vdc for 500 seconds. The voltage is then reduced to 22 vdc and the coil current measured.

- Operation (pull-in) at the maximum operating pressure (325 psig) with the minimum operating voltage (20 vdc).

- Operation (drop-out) at the minimum operating pressure (166 psig) with the drop-out voltage (1 vdc).

The results of the temperature tests are summarized in Table 2.2-I. Test specimen S/N 129 successfully passed the requirements of this test. Further discussion is contained in Appendix L, Part II, Volume II.

2.3 NON-OPERATING VIBRATION (4.7.18.1)

The purpose of this test is to demonstrate valve capabilities under a launch vehicle boost vibration environment. Vibration testing was performed dry and unpressurized on valve S/N's 129 and 130 (assembled as part of C-1 Engine Assembly (S/N's 765 and 760 respectively). The vibration requirements are indicated in Figure 2.3-1 and include sinusoidal and random spectrums. Testing was accomplished with the valve attached to the engine to ensure that the valve was exposed to actual vibration including engine amplification (See Figure 2.3-2).

ACCE

Test	Requirement		123
Coil Resistance	23 ± 1.7 ohms each coil		22.8 to 23.0
Dielectric Strength	50 μ amp max.	Coils to Body	40
		Coils to Conn.	2
Insulation Resistance	> 100 megohms	Coils to Body	35,000
		Coils to Conn.	28,000
		Coil to Coil	30,000
Pressure Drop	11 psid max.	Fuel	9.0
	14 psid max.	Oxidizer	9.9
Pull-In Voltage	≤ 20 vdc		16.3
Drop-Out Voltage	≥ 1.0 vdc		1.60
Opening Response	≤ 14 msec		8.7
Closing Response	≤ 10 msec		9.1
Internal Leakage	≤ 5 cc/hr per seat*		3.0
External Leakage	$\leq 10^{-4}$ sccps He		2.51 x 1

* Data values are for two parallel valves. Testing was accomplished to di

FOLDOUT FRAME 1

TABLE 2.1-I

PTANCE TEST DATA

	Specimen S/N 125	126	127	128	129	130
	22.1 to 22.8	22.1 to 22.7	22.1 to 22.3	22.22 to 22.34	21.9 to 22.3	22.2 to 22.7
	30	34	29	33	42	34
	30	8	1	5	1	1
	40,000	20,000	20,000	20,000	4,500	9,000
	8,600	8,600	8,600	8,600	10,000	13,000
	7,200	7,200	6,800	7,000	10,000	11,000
	9.15	10.1	9.75	10.0	10.2	9.4
	11.95	11.8	11.4	12.0	13.7	12.0
	14.8	14.9	14.6	14.0	15.3	15.8
	1.20	1.7	1.5	1.05	1.6	1.1
	8.0	8.2	8.5	8.5	8.5	9.5
	8.5	7.2	7.8	7.0	7.5	9.0
	2.5	0	4.0	1.5	4.5	4.25
0^{-0}	5.1×10^{-7}	4.4×10^{-7}	3.82×10^{-7}	4.65×10^{-7}	3.6×10^{-6}	3.3×10^{-6}

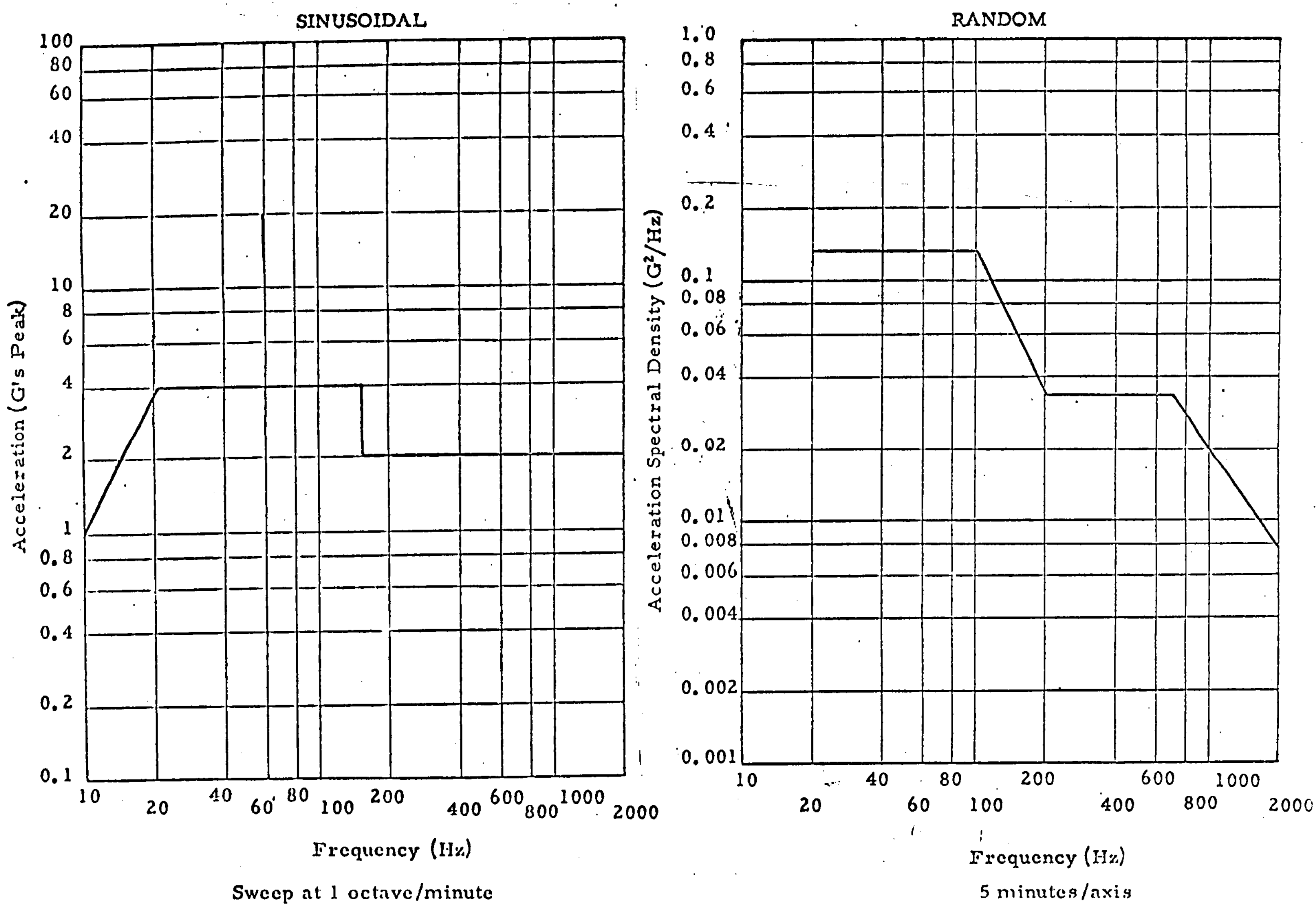
fferent specification revisions.

FOLDOUT FRAME 2

TABLE 2.2-I

TEMPERATURE TEST

Item	Conditions				Requirement	S/N 129 Demonstration
	P Inlet (psia)	Volts (vdc)	Hot Amp.	Temp. (^{o}F)		
Response						
	212	22	Yes	+180	Opening Time $\leq$ 14 msec	8.0
	212	22	Yes	+180	Closing Time $\leq$ 10 msec	7.5
	212	22	No	+12	Opening Time $\leq$ 14 msec	6.5
	212	22	No	+12	Closing Time $\leq$ 10 msec	8.5
Operation						
Pull-In	325	--	--	+180	Pull-In Voltage 20 vdc	$\leq$ 20
	325	--	--	+12	Pull-In Voltage 20 vdc	$\leq$ 20



Vibration Inputs to Engine Mounting Flange as defined in RMD Spec 15169

Figure 2.3-1. Non-Operating (Unpressurized) Vibration

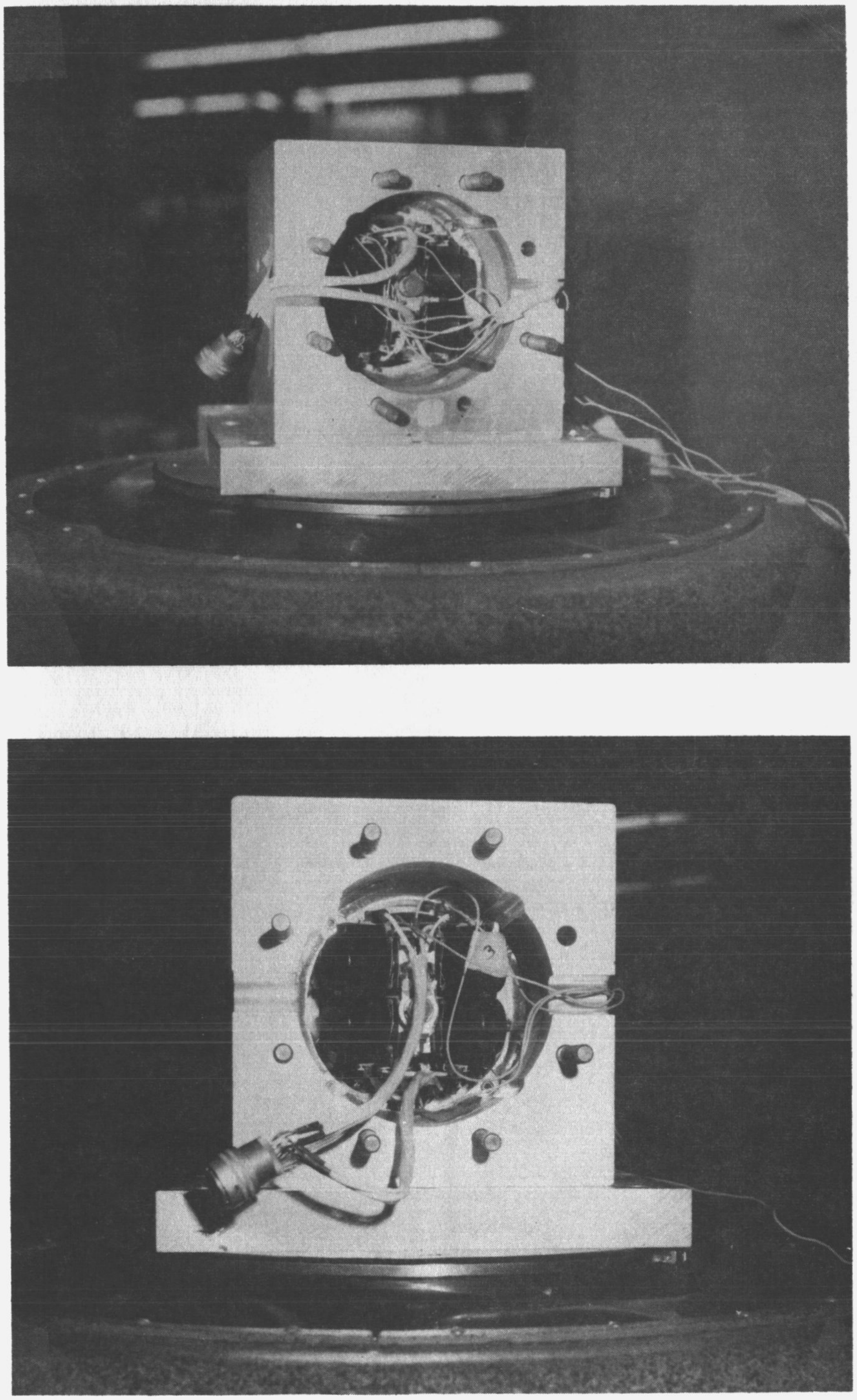


Figure 2.3-2. Quadredundant Valve Mounted in Valve-Engine Vibration Fixture

Interaxis performance testing, shown in Table 2.3-I, was conducted at the completion of each sinusoidal random vibration axes. Functional test results were satisfactory for interaxis testing. Valve seat leakage remained at zero until completion of C axis random vibration (last test) (refer to the memorandums in Appendix P, Parts III and IV). Further discussion is contained in Appendix P, Parts I and II, Volume II. A redesign and demonstration test program is currently being conducted to provide a satisfactory component. Further discussion contained in Thiokol-RMD Final Report 6203-F1 has thus far revealed the failure to be the result of flapper-to-seat relative motion, i.e., scuffing or shredding of the seat. The motion not only results in excessive seat wear but primarily causes the generation of particles or fibers, which in turn interfere with reliable sealing.

2.4 OPERATING VIBRATION (4.7.18.2)

The purpose of this test is to demonstrate valve capabilities under a spacecraft vibration environment. Vibration testing was performed wet and pressurized on valve S/N's 129 and 130, assembled as part of a C-1 Engine assembly (S/N's 765 and 760, respectively). The vibration requirements are indicated in Figure 2.4-1 and include sinusoidal and random spectrums. Testing was accomplished with the valve attached to the engine to ensure that the valve was exposed to actual vibration including engine amplification. Although the test specimens entered this test with excessive seat leakage resulting from prior non-operating vibration testing, there was no seat leakage at the completion of operating vibration testing on either specimen. The results of interaxis performance tests are presented in Table 2.4-I. It should be noted that valve S/N 131 on engine S/N 766 incurred no seat leakage during identical engine qualification operating vibration testing. Engine S/N 766 had not previously undergone non-operating vibration. Valve specimens S/N's 129 and 130 successfully passed the requirements of this test. Further discussion is contained in Appendix Q, Parts I and II, Volume II.

2.5 ACCELERATION (4.7.19)

The purpose of this test is to demonstrate valve capabilities under both launch vehicle boost and spacecraft operating environments. Acceleration testing was performed on valve S/N 123, assembled as part of C-1 Engine Assembly (S/N 760). The engine assembly

NON-OPERATING VIBRAT

RES 765 - Valve S/N 129

Valve Seat No.	Axis Vib. Type Test Seq. Press. (psig)	A Sinusoidal 1 50	 1 325	 Random 2 50	 2 3
1		None	None	None	N
2					
3					
4					
5					
6					
7					
8					

RES 760 - Valve S/N 130

Valve Seat No.	Axis Vib. Type Test Seq. Press. (psig)	A Sinusoidal 1 50	 1 325	 Randon 2 50	 2 3
1		None	None	None	N
2					
3					
4					
5					
6					
7					
8					

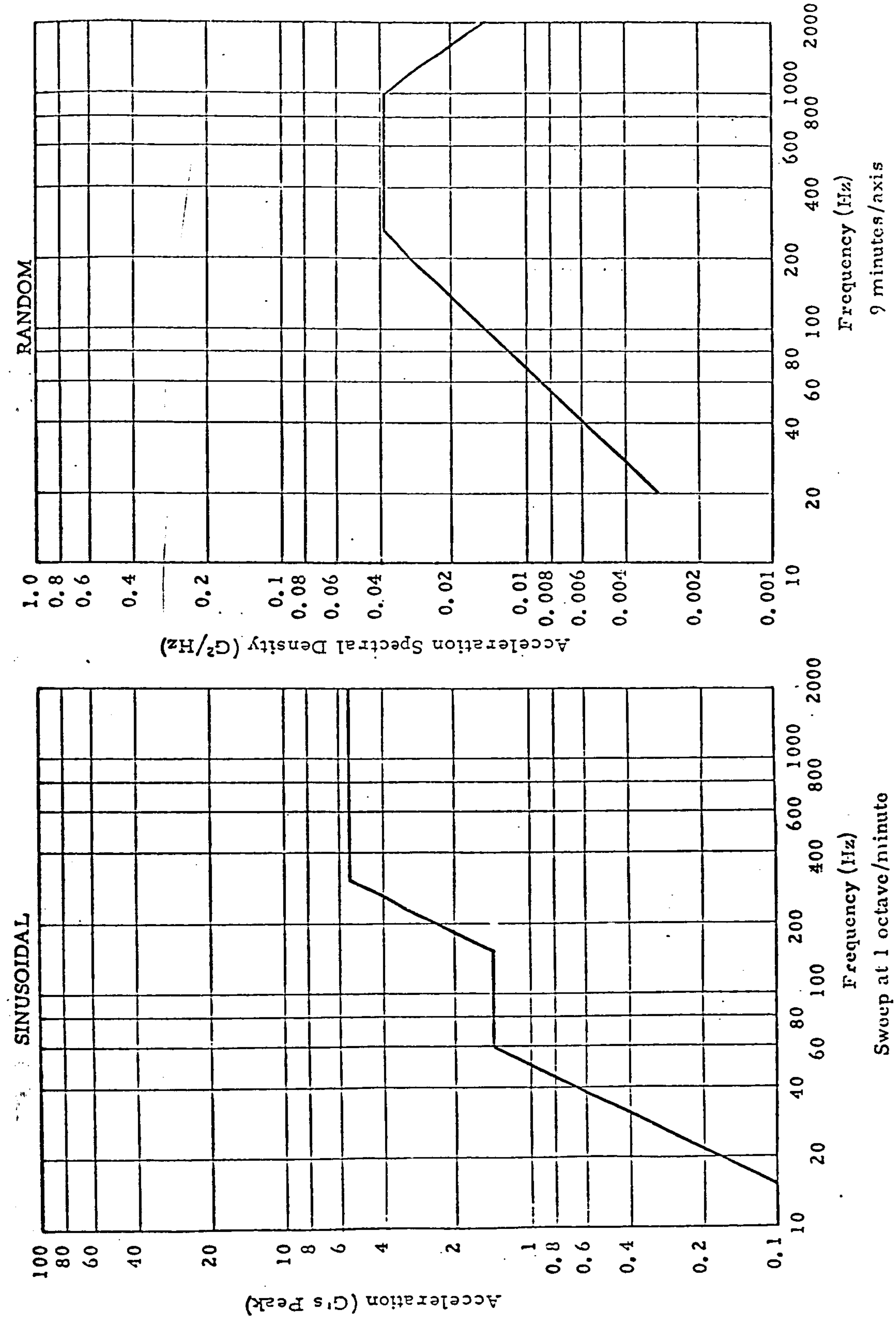
* Test results after reverse seat leakage test, pri

ION INTERAXIS LEAKAGE TEST RESULTS

	Leakage (cc/hr) at Completion of							
	B				C			
	Sinusoidal 3		Random 4		Sinusoidal 5		Random 6	
·25	50	325	50	325	50	325	50	325
one	None	None	None	None	None	None	0	-
							0	-
							0	-
							102	-
							456	-
							444	-
							720	-
							756	-

	Leakage (cc/hr) at Completion of							
	B				C			
n	Sinusoidal 3		Random 4		Sinusoidal 5		Random* 6	
25	50	325	50	325	50	325	50	·325
one	None	None	None	None	None	None	18,000	1,260
							228	0
							90	90
							162	0
							0	0
							0	0
							660	3,000
							1,200	210

or to reverse seat test, forward leakage was zero.



Vibration Inputs to Engine Mounting Flange as defined in RMD Spec 15169.

Figure 2.4-1. Operating (Pressurized) Vibration

OPERATING VIBRATION

RES 765 - Valve S/N 129

Valve Seat No.	Axis Vib. Type Test Seq. Press. (psia)	Sinusoida 50
1		None
2		
3		
4		
5		
6		
7		
8		
RES 760 - Valve S/N 130		
1		None
2		
3		
4		
5		
6		
7		
8		

(Refer to Figure 3.4-1 for leakage results prior to Ope

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TABLE 2.4-I

INTERAXIS LEAKAGE TEST RESULTS

A		B		C	
ıl & Random		Sinusoidal & Random		Sinusoidal & Random	
3		2		1	
	325	50	325	50	325
	None	0	180	5	14
	↓	0	0	8	2
		90	144	524	150
		504	240	9000	420
		36	0	90	5
		12	0	24	0
		0	0	22	4
		0	0	20	0
	None ↓	None ↓	None ↓	None ↓	None ↓

ːrating Vibration)

was mounted in a fixture simulating its normal mounting configuration and mounted on the end of the rotating arm in a centrifugal testing machine. Testing was accomplished at the following levels:

- Pressurized, Non-operating, 20 g's for 6 minutes.
- Pressurized, Operating, 20 g's for 2 minutes.

Testing was performed in each direction in each of three mutually perpendicular axes. The results of the acceleration tests are summarized in Table 2.5-I. Test specimen S/N 123 successfully passed the requirements of this test. Further discussion is contained in Appendix O, Volume II.

2.6 SHOCK (4.7.20)

The purpose of this test is to demonstrate valve capabilities under launch vehicle stage separation. Shock testing was performed on valve S/N 128, assembled as part of C-1 Engine assembly (S/N 760). The engine assembly was mounted in a fixture and secured to the platform of a shock machine. It was subjected to twenty "g" peaks, half sine wave shock pulses of ten milliseconds duration. The shocks were applied three times in both directions in each of three axes for a total of eighteen shock impacts. The results of the shock tests are summarized in Table 2.6-I. Test specimen valve S/N 128 successfully passed the requirements of this test. Further discussion is contained in Appendix R, Volume II.

2.7 HANDLING SHOCK (4.7.21)

The purpose of this test is to demonstrate valve capabilities under normal handling abuse prior to being assembled to an engine. The handling shock tests (four 45 degree edge drops and one one-inch drop on each valve face on a solid hardwood bench top) was performed on valve S/N 127. The results of the handling shock test are summarized in Table 2.7-I. Test specimen S/N 127 successfully passed the requirements of this test. Further discussion is contained in Appendix L, Part II, Volume II.

TABLE 2.5-I

ACCELERATION TESTS

Test	Requirement	Results						
		Pre-Accl	A-	(Acceleration Axis) A+	B-	B+	C-	C+
Opening Response		--	6.0	6.0	9.5	8.0	12.5	9.0
Closing Response		--	7.5	7.0	6.5	7.0	7.0	7.0
Internal Leakage *	Fuel $\leq$ 5 cc/hr per seat, gaseous	None	--	None	--	None	--	None
	Oxidizer		--	None	--	None	--	None
External Leakage*	$\leq 10^{-4}$ sccphs He.	None	--	--	--	--	--	None
Internal Leakage*	Zero, Liquid	--	None	None	None	None	None	None

* After Test Completion

TABLE 2.6-I

SHOCK TEST

After Completion Of			Axis					
			A		B		C	
Test	Requirement							
Functional	Coil		Pull-In	Drop-Out	Pull-In	Drop-Out	Pull-In	Drop-Out
	1	vdc	4.5	2.4	4.1	2.2	4.9	2.4
		ma	100	50	125	60	120	62
	2	vdc	4.7	2.3	4.7	1.8	4.6	2.5
		ma	160	70	112	60	172	76
	3	vdc	5.0	3.0	5.2	2.8	4.7	3.7
		ma	210	120	210	110	200	126
	4	vdc	4.1	2.2	4.0	1.8	4.5	2.5
		ma	100	50	120	50	98	55
	5	vdc	3.6	1.6	3.5	1.2	3.7	1.8
		ma	84	32	80	25	80	39
	6	vdc	6.1	1.4	6.2	1.0	6.5	1.6
		ma	142	30	140	22	140	28
	7	vdc	6.4	1.8	6.7	1.5	6.0	1.5
		ma	148	40	142	30	138	40
	8	vdc	4.2	1.9	3.6	1.5	4.5	1.7
		ma	105	40	142	60	100	40
Internal Leakage	200 cc/hr	Fuel	None		None		None	
		Oxidizer	None		None		None	
External Leakage	(RMD Spec 7717)*		None				None	

* Before and after completing shock tests

TABLE 2.7-I

HANDLING SHOCK TEST RESULTS

Test	Requirement	Pre-Shock	Post - Shock
Coil Resistance	23 ± 1.7 ohms each coil	22.1 to 22.2	22.2 to 22.33
Pressure Drop	11 psid max Fuel 14 psid max Oxidizer	9.4 11.7	8.7 11.3
Pull-In Voltage	$\leq$ 20 vdc	16.4	12.1
Drop-Out Voltage	$\geq$ 1.0 vdc	1.7°	1.4
Opening Response	$\leq$ 14 msec	9.0	11.5
Closing Response	$\leq$ 10 msec	7.0	7.0
Internal Leakage	$\leq$ 5 cc/hr per seat Fuel Oxidizer°	 1.2 0	 0 0
External Leakage	$\leq 10^{-4}$ sccps He.	4.25×10^{-7}	3.34×10^{-6}

2.8 LIFE TEST (4.7.22)

The purpose of this test is to demonstrate the valve capability in excess of the Contract End Item Detail Specification CP 15166 requirement of 10,000 cycles. The test was conducted at the maximum operating pressure (325 psig) by cycling the valve on and off at 10 cps. In lieu of testing only to the life requirement of 10,000 cycles, cycling was continued to failure. Valve performance parameters including response and leakage were measured every 10,000 cycles. The results of the interval performance tests are shown in Table 2.8-I.

Test specimen S/N 126 incurred a failure of the number three flexure sleeve at 43,680 cycles, cycling was continued until the number one flexure sleeve failed at 53,955 cycles.

Both number four and number five flexure sleeves failed at 77,154 cycles on test specimen S/N 127. The two specimens, S/N's 126 and 127 successfully passed the requirements of this test. Further discussion is contained in Appendix L, Part II, Volume II.

2.9 PROPELLANT COMPATIBILITY

2.9.1 FUEL COMPATIBILITY (4.7.24.1)

This test was conducted to assure valve compatibility with liquid fuel. The valve was subjected to a spray of liquid fuel maintained at +160F until all surfaces were wet and then allowed to air dry for 24 hours at 80F and ambient humidity. The test specimen, S/N 128 successfully passed the requirements of this test. Further discussion is contained in Appendix N, Part II, Volume II.

2.9.2 OXIDIZER COMPATIBILITY (4.7.24.2)

This test was conducted to assure valve compatibility with liquid and gaseous oxidizer. The tests comprised the following:

- 65F liquid oxidizer spray followed by 24 hours air dry.
- One hour exposure to oxidizer vapor followed by 24 hours air dry.

Although both coil and insulation resistance were unaffected by this test there was some reaction of the PR 1538 epoxy (Product Research Corporation) used to pot the diode in the torque motor cover cavity.

TABLE 2.8-I

LIFE CYCLE TEST

Test	Requirement	S/N 126 Pre Life Cycles	S/N 126 Post 10,000 Cycles	S/N 126 Post 20,000 Cycles	S/N 126 Post 30,000 Cycles	S/N 127 Pre Life	S/N 127 Post 10,000 Cycles	S/N 127 Post 20,000 Cycles	S/N 127 Post 30,000 Cycles	S/N 127 Post 40,000 Cycles	S/N 127 Post 50,000 Cycles
Pressure Drop	11 psid Max Fuel	10.2	9.2	9.7	9.8	8.7	9.0	8.7	9.0	9.3	9.3
	14 psid Max Oxidizer	12.2	11.7	11.8	11.6	11.3	11.5	11.4	11.6	11.5	12.1
Opening Response	14 msec	9.0	10.5	10.0	10.0	11.5	9.5	10.0	10.0	10.0	9.8
Closing Response	10 msec	7.0	7.0	7.5	6.5	7.0	7.0	7.0	7.5	7.5	7.0
Internal Leakage	5 cc/hr per seat										
	Fuel	3.5	0	3.0	1.0	0	0	0	2.0	0	0
	Oxidizer	4.0	0	0	0	0	0	0	0	0	0
External Leakage	10^{-4} sccps He.	2.1×10^{-6}	None	None	None	3.34×10^{-6}	None	None	None	None	1.78×10^{-6}

The reaction was characterized by a softening and bubbling at the surface (approximately upper 1/8 in.) of the potting material. Since there was no performance degradation, the problem in this case is one primarily of appearance. To improve the appearance and to avoid any possible effects due to extended propellant exposure, the P/N 317013-600 valves will be fabricated using Sytcast 2651 (Emerson Cummings) as the potting material for the diode cavity. This material is now used to pot the lead wire egress from each torque motor and can withstand the propellant exposures without softening. The test specimen, S/N 128 successfully passed the requirements of this test. Further discussion is contained in Appendix N, Part II, Volume II.

2.10 VACUUM (4.7.23)

These tests were conducted to assure valve electrical capabilities under a vacuum environment. Valve test specimen, S/N 130, after completion of vibration, non-operating, operating and shock was reacceptance tested prior to being subjected to the vacuum test (refer to Appendix S). The valve was installed in the vacuum chamber and subjected to 336 hours at a maximum pressure of 10^{-6} mm Hg. Prior to and shortly after reducing chamber pressure, at five-day intervals, and during the last hour at altitude, the valve was subjected to the following test sequence. Each coil of the valve was energized by slowly increasing the voltage from 0 to 30 vdc. The 30 vdc was maintained for five minutes and then decreased slowly until the valve closed. The energizing (pull-in) and de-energizing (drop-out) voltages were recorded. The valve was then cycled 100 times while the coil voltage was varied from 20 to 30 vdc. While the coils were still hot from cycling, the valve was subjected to the insulation resistance test. The values for the pull-in and drop-out voltage test and the insulation resistance test are included in Table 2.10-I. During the last hour at altitude the valve filed the 600 vac dielectric strength test. One coil intermittently arced and four shorted completely. In view of the lack of time remaining in the C-1 Engine Program, the resolution of this design deficiency will be accomplished during the redesign and demonstration program noted in Section 1.0, Part II of this report which was initiated to improve the vibrational capability of the quadredundant valve. Further discussion is contained in Appendix L, Part II, Volume II.

	Pre-Vacuum 6/10/67				6/12/67				
Torque Motor Number	Pull-in		Drop-out		Pull-in		Drop-out		
	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Volta
1	4.41	.19	2.41	.07	4.39	.19	2.21	.06	4.1
2	5.82	.25	2.98	.08	5.61	.23	2.76	.08	5.9
3	5.63	.24	3.82	.12	5.62	.24	4.10	.12	5.7
4	4.42	.19	2.78	.08	4.32	.18	2.68	.08	4.5
5	3.77	.16	1.94	.05	3.76	.16	1.83	.05	3.7
6	6.66	.28	1.64	.05	6.74	.28	1.65	.05	6.9
7	7.12	.30	2.79	.08	7.30	.31	2.40	.07	7.3
8	4.05	.17	1.84	.05	3.95	.16	2.12	.06	4.1

6/17/67				6/22/67				6/26				
Pull-in		Drop-out		Pull-in		Drop-out		Pull-in		Drop-out		Insulation R
ge	Current	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Each coil to valve body
8	.17	2.14	.06	4.09	.18	2.18	.06	4.01	.18	2.22	.07	∞
0	.24	3.19	.09	5.49	.24	2.84	.09	5.42	.24	3.14	.09	
3	.24	3.69	.10	5.49	.24	3.98	.11	5.43	.24	4.02	.12	
7	.19	2.76	.08	4.10	.15	2.88	.08	4.27	.18	2.87	.09	
2	.15	1.96	.05	3.56	.12	1.97	.06	3.56	.15	1.90	.06	
0	.28	1.86	.05	6.61	.28	1.86	.05	6.56	.28	1.83	.05	
6	.30	2.30	.06	7.07	.30	2.56	.07	7.05	.31	2.52	.07	
4	.17	2.12	.06	3.81	.16	2.20	.07	3.87	.17	2.42	.07	

TABLE 2.10-I

VACUUM TEST DATA

Model 50-304
Serial No. 130

/67			Post Vacuum 6/26/67					
esistance	Dielectric Strength		Pull-in		Drop-out		Insulation Resistance	
Each coil to other 7 coils	Parallel coil leads & valve assembly	Parallel coil leads & connector	Voltage	Current	Voltage	Current	Each coil to valve body	Each coil to other 7 coils
∞	Arcing at 440 v	1 a at 600 v	4.24	.17	2.37	.07	∞	∞
	Short at 500 v		5.64	.23	3.12	.09		
			5.62	.24	3.94	.12		
			4.21	.17	2.98	.09		
			3.66	.15	2.24	.06		
			6.80	.28	1.78	.05		
			7.25	.30	2.46	.07		
			3.95	.16	2.07	.06		

FOLDOUT FRAME 3

2.11 ELECTRICAL INTERFERENCE (4.7.13)

Test specimen S/N 128 was subjected to electrical interference testing in accordance with MIL-I-6181D. These tests were conducted to determine the following:

- the magnitude of radiated interference emanating from the valve during actuation
- valve susceptibility to radiated interference
- valve susceptibility to conducted interference

Radiated interference did not exceed MIL-I-6181D requirements. There was no evidence of valve susceptibility to either radiated or conducted interference. The valve successfully passed the requirements of this test. Further discussion is contained in Appendix M, Volume II.

2.12 FINAL PERFORMANCE (4.5.2)

Four valve specimens were scheduled for final performance testing. However, S/N 126 suffered a broken flexure tube after 43,680 cycles and S/N 130 failed the dielectric strength test. Only two valve specimens, S/N 127 and 129, were actually subjected to the final performance test which was a repeat of the original acceptance tests as described in Section 2.0 of this report. Both specimens met all requirements before and after the Qualification Test Program. Final performance (Post Qualification) and initial performance (Pre-Qualification) test data together with further discussion is contained in Appendix L, Part II, Volume II.

2.13 BURST (4.7.15)

These tests were conducted to assure valve compliance with the design requirements of Contract End Item Detail Specification CP 15166. The valve specimen, S/N 125, withstood the burst pressure (1150 psig) for two minutes, therefore successfully passing the requirements of this test. The pressure was then slowly increased until the specimen failed. Failure of the No. 8 flexure sleeve occurred at 8800 psig. The valve body evidenced no deformation or leakage at any of the weld joints when subjected to the 8800 psig pressure. Further discussion is contained in Appendix L, Part II, Volume II.